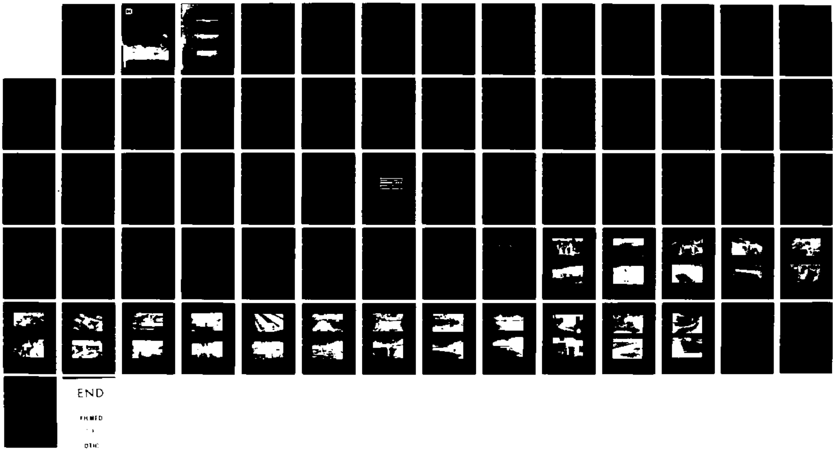
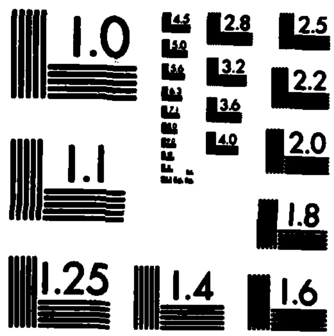
AD-A120 563 MEMBRANE-SOIL COMPOSITE LAYERS IN THE DESIGN CONSTRUCTION AND PERFORMANCE..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS GEOTE.. 1/1

UNCLASSIFIED G L REGAN SEP 82 WES/TR/GL-82-7 F/G 13/13 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TECHNICAL REPORT GL-82-7

MEMBRANE-SOIL COMPOSITE LAYERS IN THE DESIGN, CONSTRUCTION, AND PERFORMANCE OF AN EXPEDIENT BRIDGE AND APPROACH

by

George L. Regan

Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

September 1982

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Project A4A762719AT40, Task CO,
Work Unit 003

PREFACE

The investigation reported herein was sponsored by the Office, Chief of Engineers, U. S. Army, under Project No. A4A762719AT40, Task CO, Work Unit 003, "Structural Soil Construction Methods," and was conducted by the Geotechnical Laboratory (GL) of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., from October 1976 to July 1982.

The study was conducted under the general supervision of Mr. J. P. Sale, former Chief, GL, and Dr. W. F. Marcuson III, Chief, GL. The work was under the direct supervision of Messrs. A. H. Joseph and R. L. Hutchinson, Chief and former Chief, Pavement Systems Division (PSD). Engineers of the GL actively engaged with the planning, testing, analyzing, and report phases of this study were Messrs. J. W. Hall, E. R. Brown, and G. L. Regan and Dr. T. D. White. This report was prepared by Mr. Regan.

Commanders and Directors of the WES during the course of this study and the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. Fred R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
mils	0.0254	millimetres
ounces (mass) per square yard	33.90575	grams per square metre
pounds (force)	4.448222	newtons
pounds (force) per cubic foot	157.0874585	newtons per cubic metre
pounds (force) per square inch	6894.757	pascals
pounds (force) per square yard	5.32	newtons per square metre
square feet	0.09290304	square metres
tons (2000 pounds, mass)	907.1847	kilograms
tons (2000 pounds, mass) per square foot	9764.856	kilograms per square metre

MEMBRANE-SOIL COMPOSITE LAYERS IN THE DESIGN, CONSTRUCTION, AND PERFORMANCE OF AN EXPEDIENT BRIDGE AND APPROACH

PART I: INTRODUCTION

1. The U. S. Army requires expedient means of transportation in the Theater of Operations (TO). On the ground, this expediency must apply to construction operations necessary for establishment of efficient transportation networks. While long-term high-performance bridge structures, piers, and abutments are sometimes desirable in the TO, they may not be practical from a logistics standpoint.

2. There is a continuing need for development of new design and construction techniques for bridge piers and abutments suited for the TO scenario. Construction techniques in particular must allow field engineer units to make optimum use of available materials with minimum use of mechanized heavy equipment.

3. In this study, an expedient fixed bridge and approach were designed, constructed, and evaluated for potential use in TO situations. Basic materials used in the construction were timber, military stock membranes, and soil. Emphasis was on the use of membrane-encapsulated soil for the construction of piers and abutments.

Background

4. Textiles have come into increasingly frequent use by structural and geotechnical engineers. They are referred to as membranes, textiles, geomembranes, geotextiles, and by brand or trade names. Whatever term is applied to the material, it is generally understood that it describes a woven or nonwoven, natural or synthetic fabric.

5. Fabric use in engineering structures has a rather recent history. In North and South Carolina during the 1920's and 1930's, asphalt roads were constructed with cotton fabric reinforcement (*Highway and Heavy Construction* 1981 and Bushing et al. 1970). However, the

engineering use of textiles did not begin to develop fully until during the 1960's.

6. During the 1960's and 1970's, geotechnical engineers began experimenting with textile-earth composites in the form of membrane-encapsulated soil layers (MESL) in pavement structures (Sale et al. 1973), textile-confined earth retaining walls (Bell et al. 1975), membrane-strengthened retaining walls (Al-Hussaini and Perry 1976), and membrane-confined artificial islands (Engineering News-Record 1977). The concept is that of a composite soil-membrane system with tensile and flexural strengths greater than soil alone can tolerate.

MESL

7. The U. S. Army Engineer Waterways Experiment Station (WES) studies of MESL were concerned with the development and performance of membrane-surrounded soil (lean clay) as a reduced thickness component of pavements. In these applications, a 6-mil-thick* polyethylene membrane was used to encase the bottom, sides, and ends of a compacted lean clay base course. The top was covered with an asphalt-saturated polypropylene fabric. In these applications, the primary functions of the membranes were to separate and waterproof the pavement layer. Generally, the membranes were not very strong.

8. The U. S. Army Cold Regions Research and Engineering Laboratory (CRREL) has also studied the MESL concept for applications in cold weather pavements.

Forest Service
fabric-retaining walls

9. The Forest Service, U. S. Department of Agriculture, has constructed at least two retaining walls with fabric confined soil layers (Steward et al. 1977). The walls were based on model tests conducted by Stilley (Bell et al. 1975). Details of the walls are summarized below:

a. Siskiyou National Forest Wall.

BUILT: December 1974.

---

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

INSTRUMENTATION: None.

DIMENSIONS: Truncated triangle shape; 35 ft wide at the top, 5 ft wide at the bottom, and 10 ft high. About 200 sq ft total surface area.

FABRIC: Nonwoven polypropylene, 1/4 in. thick. Weight approximately 1 lb per sq yd.

SOIL: Concrete sand.

COST: Approximately $12 per sq ft of wall facing (includes cost of Gunnite application to facing, 1974 dollars).

b. Olympic National Forest Wall.

BUILT: May 1975.

INSTRUMENTATION: Vertical and horizontal inclinometers, vertical and horizontal survey monuments, and a settlement meter.

DIMENSIONS: Triangular shape; 18.5 ft high and 166 ft wide along top layer. Total surface area approximately 2100 sq ft.

FABRICS: Nonwoven polyester and nonwoven polypropylene. Weights varied from 6 to 18 oz per sq yd; thicknesses varied from 0.095 to 0.25 in.

SOIL: 3 in. maximum size, open-graded crushed rock.

COST: Approximately $11.50 per sq ft of wall facing (1975 dollars).

WES membrane-strengthened retaining wall

10. In 1976, Al-Hussaini and Perry reported on WES research into the behavior of two retaining walls. Both walls were designed to be 12 ft high, 16 ft long, and 10 ft deep. Horizontal strips, attached to the metal facing, were extended into the sand backfill where friction provided lateral restraint. Steel strips were used on one wall and membrane was used on the other.

11. A 4-ply woven nylon, neoprene-coated membrane was used. As the membrane strip wall reached a height of 10 ft, it collapsed. The authors concluded that membrane deformations, exceeding those required to develop active earth pressure in the backfill, caused the wall to tilt excessively and collapse.

Membrane-confined sand island

12. In October 1976, a membrane-confined sand island and deck structure failed in heavy seas and high winds near England (Engineering News-Record 1977). An offshore-type deck was attached to a membrane filled with sand. The sand island base extended to the seabed about 50 ft below water level. Specifics of the base were as follows:

APPROXIMATE HEIGHT: 32 ft.

SHAPE: Truncated cone with 29-ft-diam top and 4-ft-diam base.

MEMBRANE: 0.19-in.-thick neoprene reinforced with nylon.

CONSTRUCTION TIME: 12 hr.

CONSTRUCTION METHOD: 2500 tons of sand was placed in membrane bag using conveyors from ships. Water was pumped from the bag as sand filled it.

PROJECT COST: $400,000.

WES membrane-sand bridge abutment

13. During the mid 1970's, Webster and others of WES (Webster 1975) constructed an expedient bridge abutment of sand, lumber, nails, and membrane (rubber-coated woven textile). It was built to determine the feasibility of constructing such a structure in the military TO. No design procedure was developed. They found this kind of construction could be accomplished with limited personnel and equipment.

14. WX-18 membrane, a heavy-duty 4-ply woven nylon fabric coated with neoprene, was cut, formed, and filled with sand to build a six-layer vertical abutment. In effect, each layer was a giant sandbag. Nominal layer dimensions were 12 ft long, 8 ft wide, and 1.5 ft high making the abutment 9 ft high. Construction was completed in 10 hr by a crew of four, a foreman, a heavy equipment operator, and miscellaneous equipment. Work started after all materials were on site.

15. Figures 1 and 2 show membrane pattern and overall design of Webster's membrane-sand abutment.

Summary remarks

16. The previous examples of construction with membranes, fabric, and earth materials illustrated a wide range of uses of engineering fabric. Fabrics and the science of using them are still evolving,

opening the potential for even more applications.

17. Since the military has existing stocks of membranes and almost any TO has soil available for use, it seems reasonable that these resources be used in expedient construction operations where time is short and mechanized heavy equipment is limited.

Purpose and Scope

18. The purpose of this report is to present details of the design, construction, and performance of an expedient experimental bridge abutment and piers. Design and construction of the superstructure were performed using standard timbers. The substructure and an approach were built of soil confined with military stock membranes. In this report, the word "design" is used relative to proportioning membrane-soil components; lateral earth pressures and membrane stresses were not computed.

19. Construction was limited to a 3-span, simply supported, 12-ft-wide, single-lane bridge with nominal 22-ft spans. The bridge crossed a major drainage creek whose basin is partially located within WES. Construction was done entirely within WES boundaries.

PART III: CONSTRUCTION

24. Construction of the bridge super- and substructures was accomplished with a four-man crew and one equipment operator. Work started 17 October 1977 and was concluded 15 November; this time frame includes weekends, time when unanticipated problems occurred, and periods of rainfall and runoff when work was not done.

25. Total time for the construction was approximately 652 man-hours. This was done in about 15.5 effective days with the crew working a maximum of 10-hr days. A field unit of 16 or more troops should be able to construct the same bridge in about 40 hr or less.

Support and Approach Materials

26. The substructure support system consisted of four separate vertically stacked, layered structures. Each layer was made of sand surrounded by stacked sandbags inside a cut and formed rectangular membrane for confinement. A layered membrane confined approach (abutment) was built with membrane, sandbags, and lean clay soil. These materials are further described below.

Membranes

27. The heavier T-17 membrane was used in most of the construction with T-16 substituted after depletion of T-17 stock. Only the upper two layers of the layered approach were constructed with the lighter duty (T-16) membrane.

28. T-17 is a multi-ply membrane, weighing about 48 oz per sq yd, constructed of 2 plies of woven fabric coated with neoprene rubber; it has a thickness of about 0.046 in. T-16 is made with a neoprene rubber compound but has only a single ply of woven nylon fabric; it weighs about 16 oz per sq yd and has a total thickness of about 0.019 in. Tables 1 and 2 contain additional data on these membranes. Figures 8 and 9 show typical uniaxial stress-strain characteristics of the membranes based on 2-in. cut strip tests.

PART II: BRIDGE DESIGN

Timber Superstructure

20. Design of the bridge's timber superstructure was performed using guidelines appropriate to TO conditions (Department of the Army 1969; see Army FM 5-34, Chapter 7, Section II). Figures 3 and 4 indicate, respectively, cross sections of the timber structure and a cross section of the creek with the supporting structure shown.

21. Based on the design, stringer classification considering moment and shear for the single-lane bridge was 30 for tracked and 30 for wheeled vehicles. However, the 3-in. deck classification controlled the design with a nominal class rating of 8.

Layered Supports

22. Four vertical supports built of membrane-confined sand layers were designed to transfer applied loads to the foundation soil. Supports were numbered consecutively from south to north. Foundation layers were generally proportioned 6 × 14 ft with a height of about 1.5 ft. A layer of compacted sand was sandwiched between the foundation soil and the bottom/foundation layer. Upper membrane-confined layers were designed 4 × 12 ft with variable heights. Figure 5 illustrates the general design of the supports.

Approaches

23. Cut and filled approaches were necessary for traffic access to the bridge. On the north side abutting support 4, a layered membrane-confined soil approach was provided. Sectional and side views of this approach are shown in Figures 6 and 7. The south approach was designed as a cut into existing soil that formed a terrace adjacent to the creek.

Soils

29. Soils used in this project were locally available concrete sand and a local lean clay soil. Sand was used in building the bridge supports and lean clay was used in the layered approach.

30. Gradations of each soil used are shown in Figure 10. Direct shear test results from the sand are given in Figure 11. Additional data for the concrete sand are provided in the following tabulation (dry unit weights were tested using the method outlined in Department of the Army (1970)):

Specific gravity	2.65
Laboratory maximum dry unit weight	117.7 pcf
Laboratory minimum dry unit weight	98.2 pcf
Coefficient of uniformity	2
Mean diameter	0.5 mm

Sandbags

31. Sandbags used in this project were 14 × 26 in. in size and were made of jute or kenaf burlap.

Superstructure Materials

32. The timber superstructure was constructed of the following materials subdivided by components (all timber was creosote-treated):

a. Stringers, 8 × 16 in., 22-ft lengths.
b. Bearing pads, 3 × 12 in., various lengths.
c. End dam,* 3 × 12 in., 12-ft lengths.
d. Decking, 3 × 12 in., 12-ft lengths.
e. Tread, 2 × 12 in., various lengths.
f. Curb, 2 × 6 in., various lengths.
g. Stringer connectors, 1/4 × 6 × 24 in. steel plates (8).
h. Stringer connector nuts and bolts, 16-in.-long, threaded bolts with matching nuts.

---

* An end dam is a timber abutment component that bridges the ends of the stringers. It prevents soil movement in the longitudinal direction.

Other Materials and Equipment

33. Additional materials and equipment used in construction of the bridge included:

a. Nails.

b. Plywood boards, 3/4 in. thick.

c. Sandbag stands/holders.

d. Hammers.

e. Shovels.

f. Mechanical and hand compacting equipment.

g. Backhoe (to speed excavation for supports, optional).

h. Small bulldozer (to move soil, necessary).

i. Forklift (to transport pallets of sandbags, optional).

j. Front end loader (to speed placement of soil, optional).

k. Mobile crane (to lift and guide stringers, necessary).

l. Level/transit and rod.

m. Airfield index penetrometer or other field soil indexing apparatus.

n. Gasoline-powered generator capable of powering circular saw and drill.

o. Circular power saw and replacement blades.

p. Power drill and drill bits.

q. Gasoline-powered chain saw.

r. Adequate supply of fuel (diesel and gasoline).

s. Pry bars.

t. Carpenter's level.

u. Tapes (long and short, i.e., 100 ft and 12 ft).

v. Knives.

w. Assorted wrenches.

Construction Details

34. Prior to any excavation or start of bridge construction, all materials were moved to the site. Sandbags were filled, stored, and covered (Photos 1 and 2). Membrane bag patterns were cut from large

rolls of membrane; this is shown in Photo 3. The pattern used is shown in Figure 12, and general bag construction details are shown in Figure 13.

Horizontal and vertical control

35. During construction, a system of horizontal and vertical control points was established on and around the bridge. It was designed to provide reference points for monitoring horizontal and vertical movements of the bridge components during the performance evaluation period.

Layered support (pier) construction

36. All layered supports (piers) were constructed with the surface of the first membrane-confined layer approximately flush with ground level. Additional layers of smaller cross section were built above the base until the design elevation was reached. Steps in the construction were as follows:

a. Excavated soil and support (pier) locations with backhoe (Photo 4).

b. Trimmed bottom of excavation (Photo 5).

c. Placed flat membrane layer in excavation and stacked protective sandbags on creek side of excavation to resist scour (if adjacent to creek) (Photo 6).

d. Placed and leveled sand to desired base elevation of the first membrane-confined layer (Photo 7).

e. Assembled and formed bottom and sides of membrane bag (Figure 13).

f. Placed membrane bag on the base with top flaps folded out.

g. Stacked sandbags around inside of membrane bag (Photo 8).

h. Filled and compacted sand in approximate 6-in. layers and compacted each layer with either mechanical or hand compaction equipment (Photo 9).

i. Folded flaps and nailed membrane to plywood to close and confine the layer (Photos 10 and 11).

j. Backfilled and compacted soil around bottom membrane-confined layer.

k. Repeated steps e through i until desired support (pier) elevation was reached.

37. Photos 12 through 14 illustrate the construction sequence for upper support layers. Supports 1 through 4 are shown at finished elevations in Photos 15 and 16.

38. Typical bottom layer dimensions were approximately 6 × 12 ft with height varying between 1-1/4 and 1-1/2 ft. Upper layers were about 1 to 1-1/2 ft thick and were 4 × 12 ft long. A summary of layered support (pier) construction data is given in Table 3.

Timber superstructure

39. A timber superstructure was constructed above the membrane-confined sand supports. The order of construction was as follows:

a. Bearing pads were partially built on each of the four supports using 3 × 12 in. timbers (Photo 17). Their function was to distribute loads to the supports and to hold the stringers in position.

b. The 22-ft-long stringers were placed across the supports with the aid of a crane.

c. Abutting stringers were bolted together (Photo 18).

d. Pads were completed and stringers were nailed to the pads for lateral restraint (Photos 19 and 20).

e. Decking was placed (Photo 21), nailed into place, and trimmed.

f. End dams, treads, and curbs were placed.

g. Reference (survey) points were marked on top of treads above each support.

Approach construction

40. The bridge was designed and built with a south approach cut into natural ground and a north approach fill built of membrane and lean clay. Plans were to use T-17 membrane in the north approach. When the supply was exhausted, T-16 was substituted in the upper two layers.

41. Photo 22 shows the start of grading for the south approach where no layered construction was required.

42. General steps in the construction of the north approach were as follows:

a. A field cut length of membrane was laid out over the surface soil.

b. Filled sandbags were placed along membrane at the locations of east and west faces of the retaining structure. They were stacked one bag wide and two to three bags high (See Figure 14, Technique 1).

c. Membrane was folded over the sandbag faces toward the interior of the approach.

d. Sandbags were placed above the folded membrane to hold it in place.

e. Soil was placed above the membrane and compacted in about 6-in. lifts until the layer reached design height.

f. Steps a through e were repeated until the approach reached design height.

g. A layer of crushed limestone was placed above the top layer. (Note: Use of limestone is not necessary; however, a protective layer of available soil or multiple layers of membrane could be used to protect the top membrane-soil layer from direct tire/track contact and damage.)

Layered approach construction techniques

43. The preceding general steps were followed; however, construction problems led to the use of two building techniques on the north approach. In the first technique, shown in Figure 14, facing sandbags were stacked three layers high, membrane was not overlapped at the interior, and inner sandbags were placed adjacent to facing sandbags to hold membrane in place. This technique was used on the lower three layers. As the approach was built higher by filling and compacting the lean clay soil, more outward leaning and lateral movement of the wall faces was observed. Technique 1 and the effect of using Technique 1 can be seen in Photos 23 and 24, respectively.

44. To minimize lateral spreading in the upper three layers, a second technique which is also shown in Figure 14 was used. Sandbags along the faces were stacked two bags high, tension was applied to the membrane, it was overlapped at the interior, and sandbags were placed above the overlap before filling and compacting the soil. This technique is shown in Photo 25. Table 4 summarizes construction data for the layered approach.

Anchoring and seating the superstructure

45. After the north approach had been built, the timber superstructure was anchored to the upstream banks with four deadman anchors

and cable. Photo 26 shows the anchors and bridge during a typical storm.

46. The timber structure was seated on its layered supports with several passes of a bulldozer, as shown in Photo 27. This completed the construction phase of the project.

PART IV: PERFORMANCE

47. The bridge was observed during the performance evaluation period, 16 November 1977 until July 1982. During this time, elevation data and notes were recorded and photographs were taken.

Traffic

48. Specific traffic loadings were not applied to the bridge during the performance period. However, initial traffic during the first week after construction included:

a.	D-4 Caterpillar dozer (Photo 27)	- 6 passes
b.	Large forklift	- 2 passes
c.	Dump truck (5-cu-yd)	- 2 to 3 loaded passes - 2 to 3 empty passes
d.	Stake-body truck (lightly loaded)	- 8 passes

Additional uncounted intermittent traffic, consisting primarily of light-duty vehicles such as 1/2 ton pickup trucks and carry-all crew vehicles, was applied to the bridge throughout the evaluation.

Scour/Erosion and Sediment Deposition

49. During the evaluation period, scour/erosion was a continuing problem on the upstream end and the sides of supports 2 and 3. Sandbags filled with a mixture of cement and clay gravel were placed in the affected areas twice during the evaluation period due to frequent downstream movement of the protective sandbags caused by runoff currents. During the evaluation period, the scour/erosion did not adversely affect bridge performance, but it did require maintenance to prevent major damage.

50. Early in the evaluation period, erosion was noted around the two interior span supports. Since debris had collected around the downstream end of the two interior anchoring cables during periods of runoff,

the cables were believed at least partially responsible. They were dismantled, leaving the two exterior cables restraining the timber superstructure.

51. Erosion continued on an intermittent basis during periods of high runoff. At the end of the performance period, it had widened the creek about 7 ft between supports 2 and 3; this caused the creek to extend from one support to the other. Scour had also deepened the creek in this area. Photo 28 shows the creek and bridge at the end of construction. Support 2 was built about 4 ft north of the creek edge and support 3 was built about 3 ft south of the creek. Photo 29 shows erosion effects at support 2 toward the end of the evaluation period.

52. The cause of this scour/erosion between supports 2 and 3 was reduction in stream cross-sectional area during high water due to bridge construction. For a frequently experienced water surface elevation in the range 137 to 138 ft mean sea level (msl) (2 to 3 ft below the stringers), the supports and north approach reduced the original cross-sectional area to approximately 69 percent of original area and increased average stream velocity about 46 percent. Most of the higher velocity flow occurred between supports 2 and 3.

53. During the performance period, sediment was deposited to a depth of 1-1/2 to 2 ft on both upstream and downstream sides.

Bridge Settlement

54. Bridge settlement was periodically monitored using a system of reference points on the treads of the timber structure above each support. These data are shown in Figures 15 through 18. Longitudinal data are summarized in Figure 19. Settlements occurred as indicated in Table 5.

55. As expected, deck settlement above supports 2 and 3 was considerably greater than above the other supports. If settlements of this magnitude or greater were a problem in a particular situation, jacking and shimming could be used to level the timber structure.

Layered Supports

56. Layered supports were to be monitored for settlement and volume changes; however, due to flooding, scour, erosion, and deposition, some of the reference points were lost. Collected data included vertical movements of some support layers and lateral movements of some layers along the long dimension. These data were used to estimate total downward movement of supports 2 through 4. Results are shown in Table 6. Estimates indicate that downward movement consisted of base settlement and layer shortening. Layer shortening was caused primarily by lateral spreading of the membrane-confined layers during the evaluation period. Results in Table 6 generally agree with bridge settlement data in Table 5.

57. As expected, data showed considerably more measured settlement at supports 2 and 3 than at support 4. Converted airfield index penetrometer readings for the upper 6 in. of foundation soil indicated similar relative strengths at the base of supports 3 and 4. Average converted CBR readings were 2.2 at support 3 and 2.5 at support 4. Greater dead loads and live loads on supports 2 and 3 caused the increased settlements of these supports. Scour during periods of runoff probably also had an effect.

Layered Approach

58. The layered approach performed well in general; however, both faces of the approach exhibited problems. The two problems that occurred were defined as:

a. Type 1. Outward rotation of the stacked sandbag faces about their supports, exposing confined soil to environmental forces.

b. Type 2. Tensile failure of the confining membrane, exposing the confined soil.

59. Type 1 (rotation) problems occurred on both faces of the approach in the third layer. This problem was caused by the method of construction. Construction Technique 1 provided restraint to lateral

earth pressures only at points of contact between layers, i.e., at the top and bottom of each 1.2- to 1.4-ft-high layer.

60. By the end of construction of Layer 3, lateral movement/outward leaning had occurred to such an extent that another technique was developed to prevent similar movement in upper layers. Construction Technique 2 basically placed the membrane in tension as construction progressed and used a layer 0.9 to 1.0 ft high. It was essentially a prestressed membrane resisting lateral earth pressures with tensile forces in the membrane created by the weight of soil and soil-membrane frictional forces.

61. Photos 30 through 33 illustrate the movement and positions of the layered approach. Layer 3, with the most unstable faces during construction, experienced the most lateral movement. Rotation of its faces continued throughout the evaluation period. Photos show that upper layer faces shifted or rotated down to protect underlying unprotected soil. This upward-moving, progressive lateral reorientation of faces provided an unexpected degree of protection to lower lying soil layers.

62. Type 2 (tensile) failures were noted in the lighter duty T-16 membrane toward the end of the evaluation period (during May 1981). Tensile stresses and conditions such as exposure to sun, rain, and heat combined to create the type of failure illustrated in Photo 34. These failures were noted only in Layer 5 on the west face at stress points toward the ends of interior sand bags.

63. This type of failure was limited to the second construction technique (prestressed membrane) and the single-ply membrane; it indicated that the membrane was performing its intended function of providing lateral restraint to the confined soil. It also indicated that the lighter duty membrane was not as durable in resisting earth pressures and environmental forces as the heavier membrane.

64. Performance of the T-17 membrane was excellent. No signs of significant deterioration were noted during the evaluation period.

Recommendations

66. Based on this study, the following recommendations are made:

a. The concept of membrane-confined soil layers should be further studied for potential use in both military and civilian applications. Simple construction with a minimum of heavy equipment are key strong points of the concept. Other potential TO wall/pier applications include bunkers and aircraft revetments.

b. Field construction demonstrations with these types of components should be performed at various military installations making full use of troop labor and equipment. Construction and performance data could be compiled on a variety of structures, loading conditions, and climates.

c. Construction and performance of similar structures designed for load class 60, high-volume traffic should le evaluated.

d. In design and construction of layered approaches, a modified technique, consisting of a more stable sandbag arrangement along the facing, should be used. A recommended facing technique, using staggered sandbags, is shown in Figure 20.

PART V: FINDINGS AND RECOMMENDATIONS

Findings

65. The following general findings summarize the construction and performance phases of this project:

- a. Bridge construction using membrane-confined soil layers and timber proved feasible.
- b. Construction was simple and can be fast; techniques used should be readily adaptable for use in TO conditions.
- c. Construction methods are flexible and can be accomplished using common construction tools and a minimum of heavy equipment.
- d. Membrane-confined layered supports performed satisfactorily during the evaluation period.
- e. The timber superstructure performed well.
- f. The layered approach performed well, except that rotation continued in both faces of the third construction layer. This was due to a method of construction which was later changed.
- g. Scour/erosion protection measures were not adequate for long-term protection of interior support foundations (supports 2 and 3). In this project, such protective measures were not initially considered. It proved possible to control scour through periodic maintenance based on semiannual inspections. Because this type of expedient bridge substantially reduced the stream cross section during periods of high flow, scour protection was important in this long-term application.
- h. Performance of T-17 membrane was excellent with no noticeable signs of significant deterioration.
- i. Environmental forces, such as sunlight and heat, combined with internal stresses in the T-16 membrane to initiate several small areas of tensile failure. It began showing signs of distress after less than 4 years under these test conditions. Lighter duty T-16 membrane is not as durable for extended exposure and use in soil-membrane structures as T-17.
- j. Overall performance of the bridge was excellent.

Table 1

T-16 Membrane Properties

Approximate weight	16 oz per sq yd
1-in. cut strip (ASTM D 1682)	
Warp strength	336 lb at 25 percent elongation
Fill strength	219 lb at 26 percent elongation
2-in. cut strip (ASTM D 1682)	
Warp strength	506 lb at 21 percent elongation
Fill strength	547 lb at 29 percent elongation
Grab (ASTM D 1682)	
Warp strength	440 lb at 26 percent elongation
Fill strength	395 lb at 32 percent elongation

Table 2

T-17 Membrane Properties

Approximate weight	48 oz per sq yd
1-in. cut strip (ASTM D 1682)	
Warp strength	631 lb at 29 percent elongation
Fill strength	442 lb at 25 percent elongation
2-in. cut strip (ASTM D 1682)	
Warp strength	1438 lb at 34 percent elongation
Fill strength	1102 lb at 30 percent elongation
Grab (ASTM D 1682)	
Warp strength	917 lb at 28 percent elongation
Fill strength	736 lb at 30 percent elongation

REFERENCES

Al-Hussaini, M. M., and Perry, E. B. 1976. "Effect of Horizontal Reinforcement on Stability of Earth Masses," Technical Report S-76-11, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Bell, J. R., et al. 1975. "Fabric Retained Earth Walls," Proceedings of the Thirteenth Annual Engineering Geology and Soils Engineering Symposium, University of Idaho, pp 271-287.

Bushing, H. W., et al. 1970. "A State of the Art Survey of Reinforced Asphalt Paving," Proceedings of the Association of Asphalt Paving Technologists, Vol 39, pp 766-798.

Department of the Army. 1969. Engineer Field Data, Field Manual (FM) 5-34, Washington, D. C.

__________. 1970. Laboratory Soils Testing, Engineer Manual (EM) 1110-2-1906, Washington, D. C.

Engineering News-Record. 1977. "New Use Sought for Sand Island," Vol 198, No. 3, p 27.

Highway and Heavy Construction. 1981. "Construction Fabrics; State of the Art Report," Vol 124, No. 8, pp 47-57.

Sale, J. P., et al. 1973. "Membrane Encapsulated Soil Layers," Journal of Soil Mechanics and Foundations Division, American Society of Civil Engineers, Vol 99, No. SM-12, pp 1077-1108.

Steward, J. E., et al. 1977. "Guidelines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads," U. S. Department of Agriculture, Forest Service; also printed as FHWA Report No. FHWA-TS-78-205, 1978.

Webster, S. L. 1975. "Construction of Sandbag Bridge Abutments," U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Table 6

Estimated Downward Movement of Layered Supports

(From Recorded Data)*

Support Number	A Layer Number	B Initial Height of A	C Measured Shortening of A	D Initial Support Height	E** Computed Total Shortening	F Measured Settlement	G** Estimated Total Downward Movement
2	3,4,5,6	5.01	0.08	7.52	0.12 (1.4 in.)	0.16 (1.9 in.)	0.28 (3.3 in.)
3	4,5,6	3.91	0.10	7.56	0.19 (2.3 in.)	0.14 (1.7 in.)	0.33 (4.0 in.)
4	3,4,5	4.28	0.09	6.66	0.14 (1.7 in.)	0.03 (0.3 in.)	0.17 (2.0 in.)

* All quantities are in feet except as indicated.

** $E = \frac{CD}{B}$; $G = E + F$.

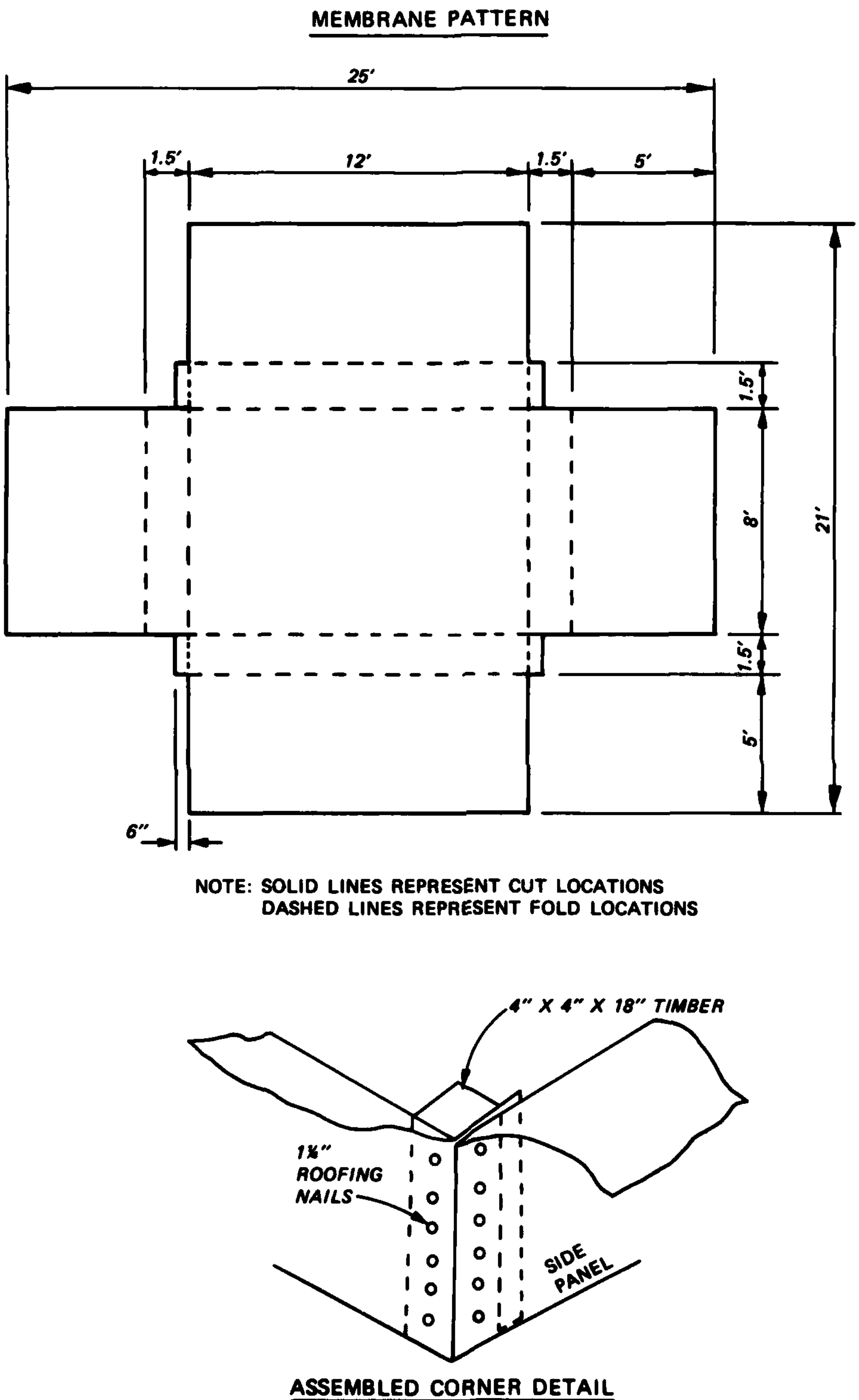


Figure 1. Membrane sandbag design (from Webster 1975)

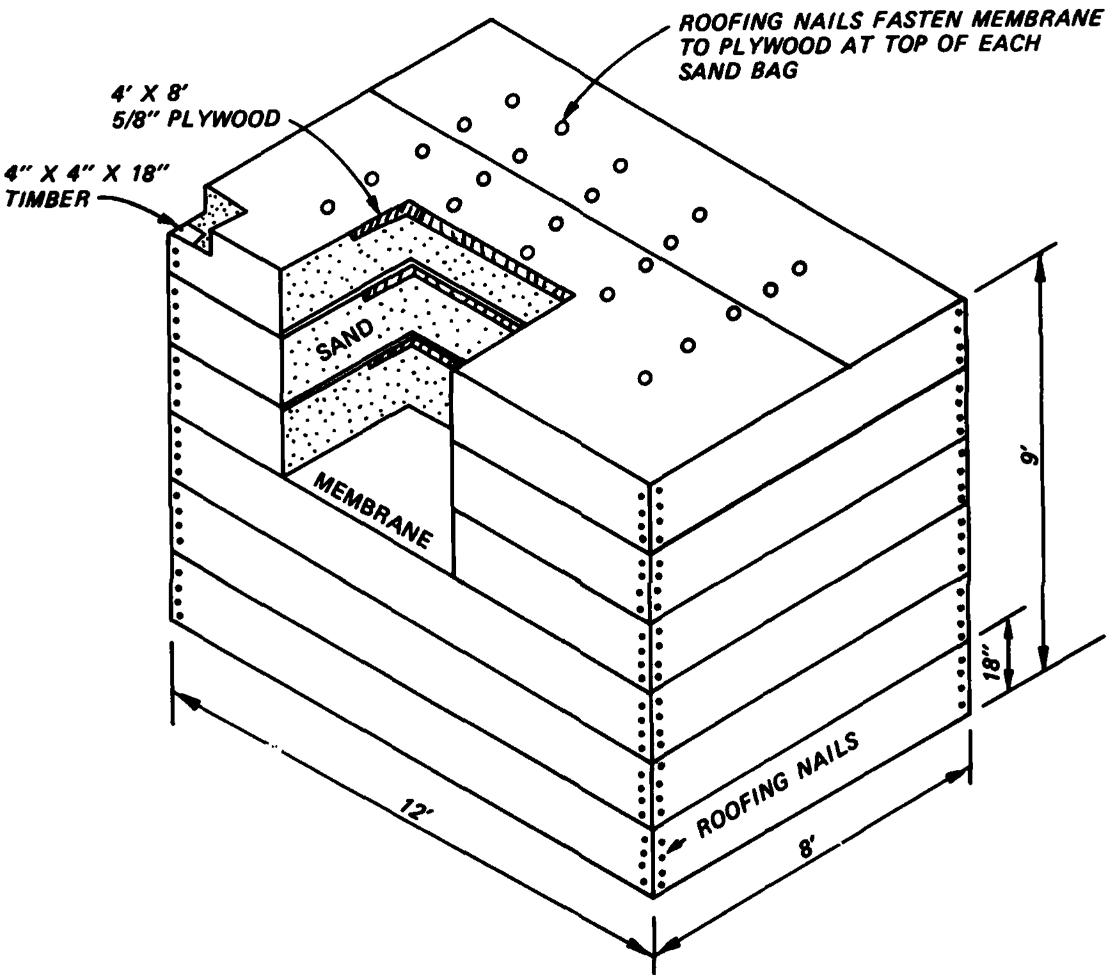


Figure 2. Sandbag bridge abutment (from Webster 1975)

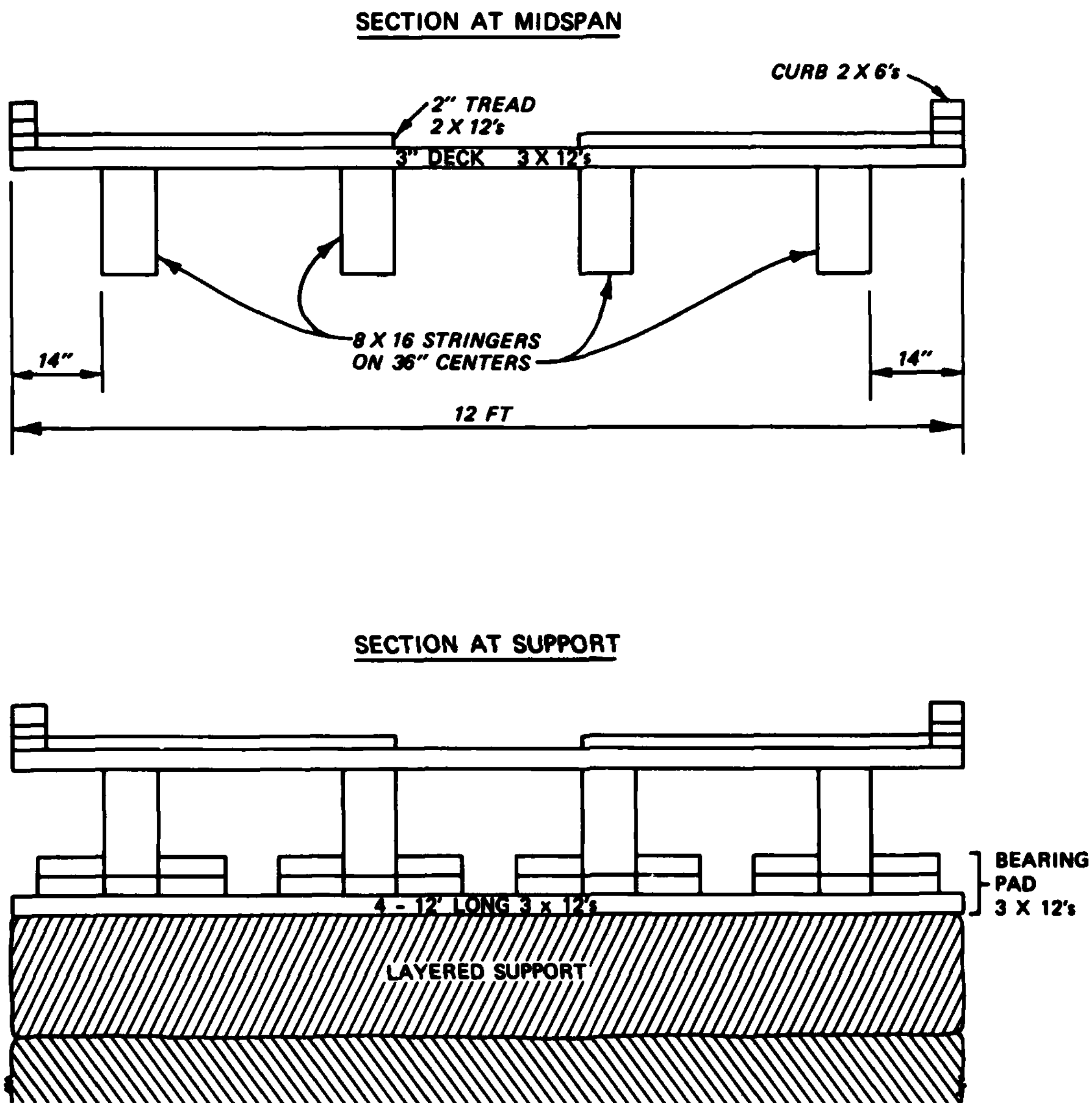


Figure 3. Bridge cross sections

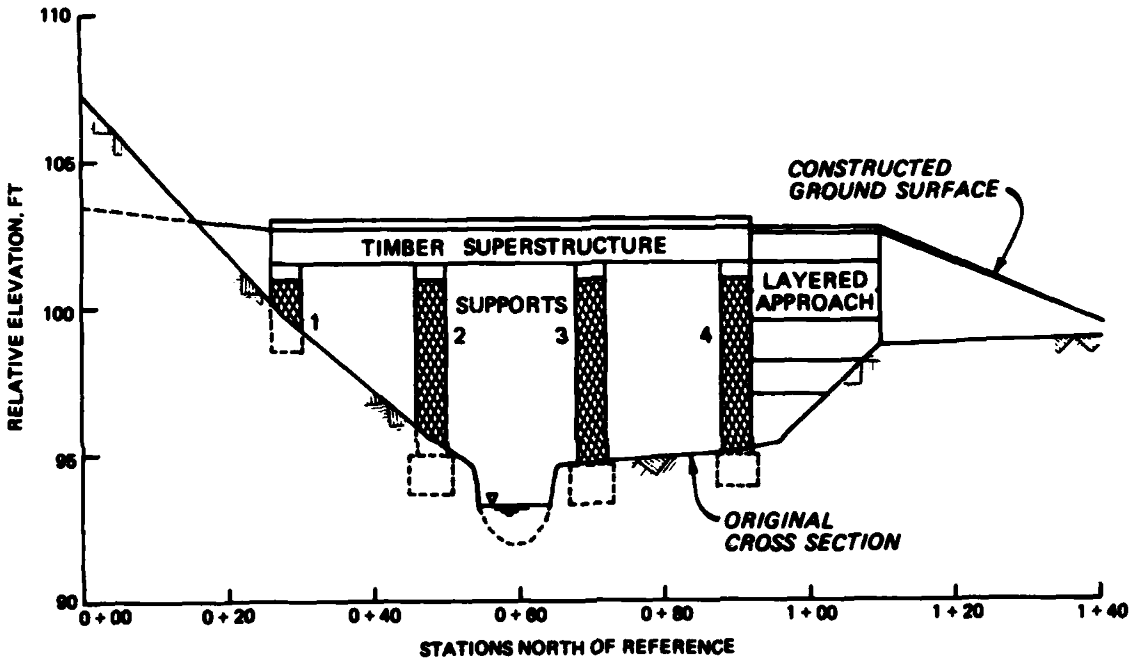


Figure 4. Original cross section along bridge centerline showing support locations

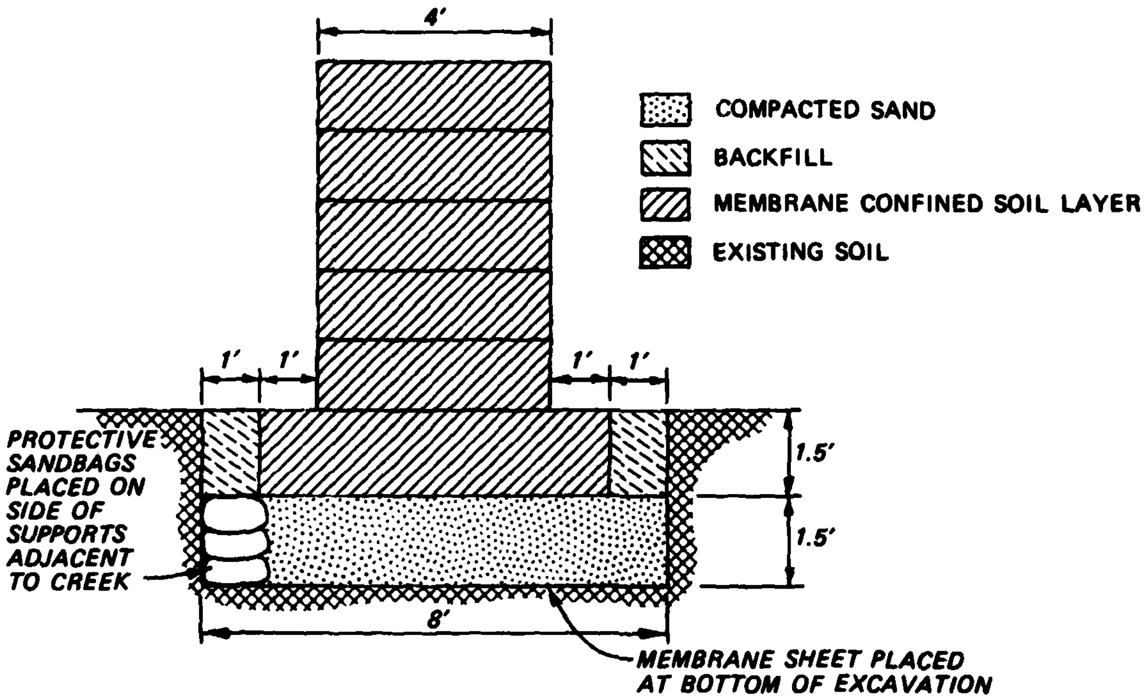


Figure 5. Membrane confined soil support and foundation

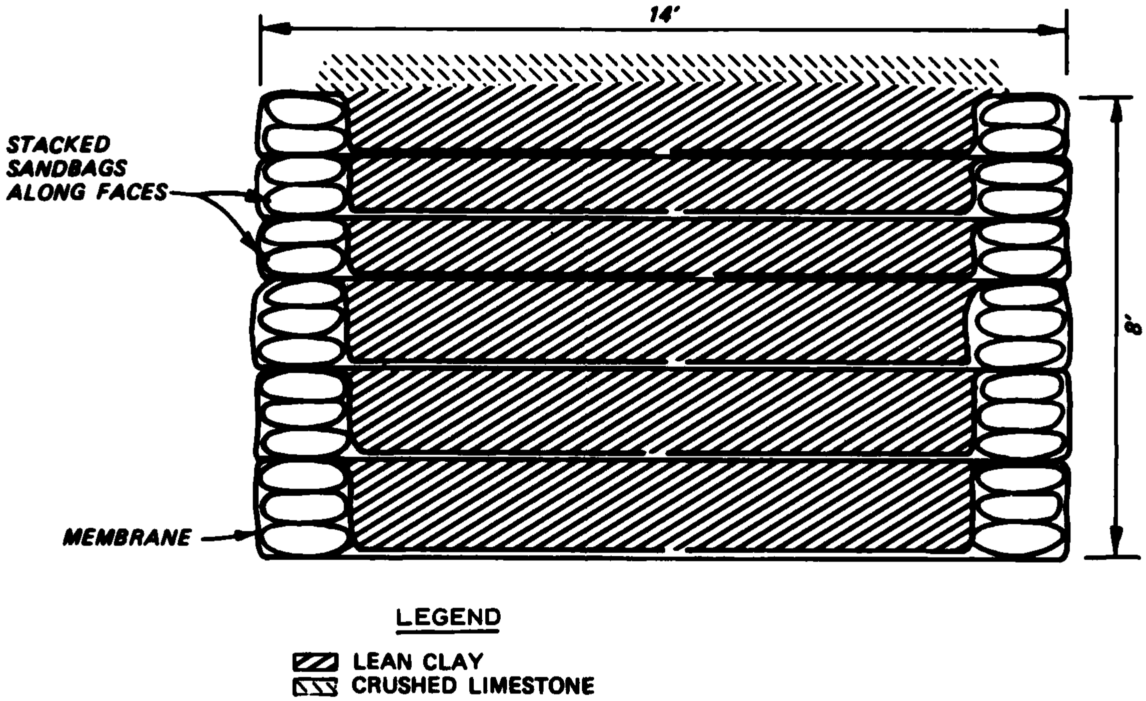


Figure 6. Layered approach cross section

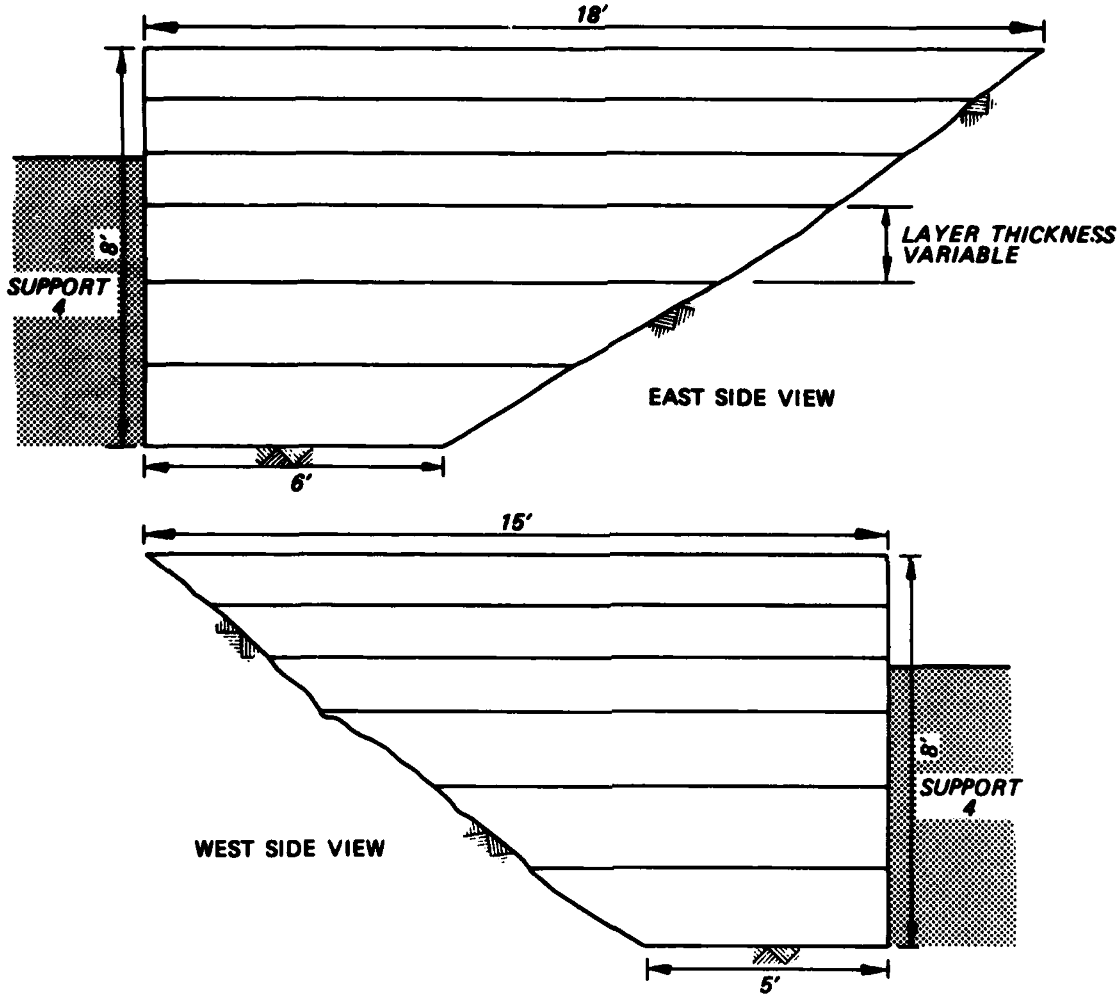


Figure 7. Layered approach side views

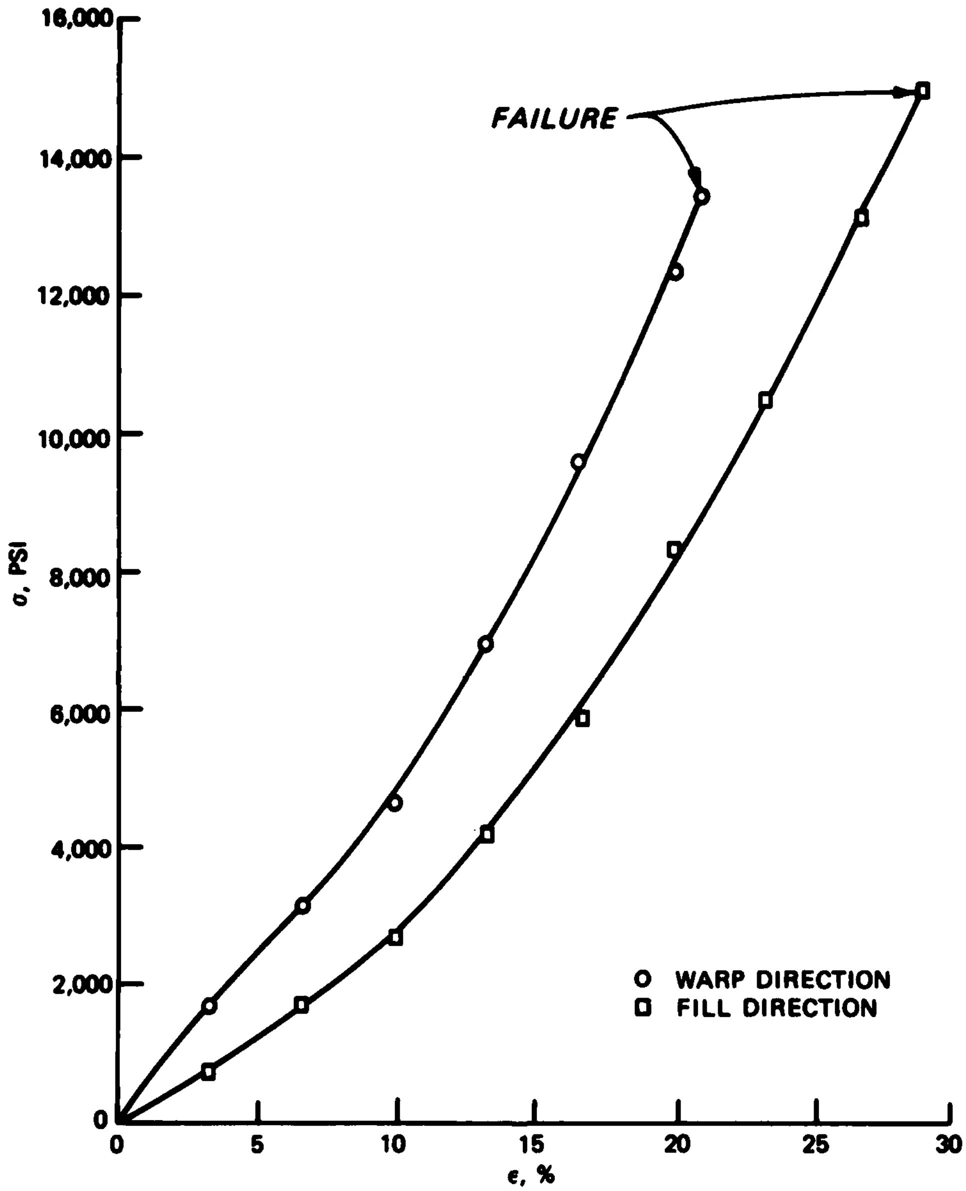


Figure 8. Uniaxial stress-strain characteristics of T-16 membrane (2-in. cut strip)

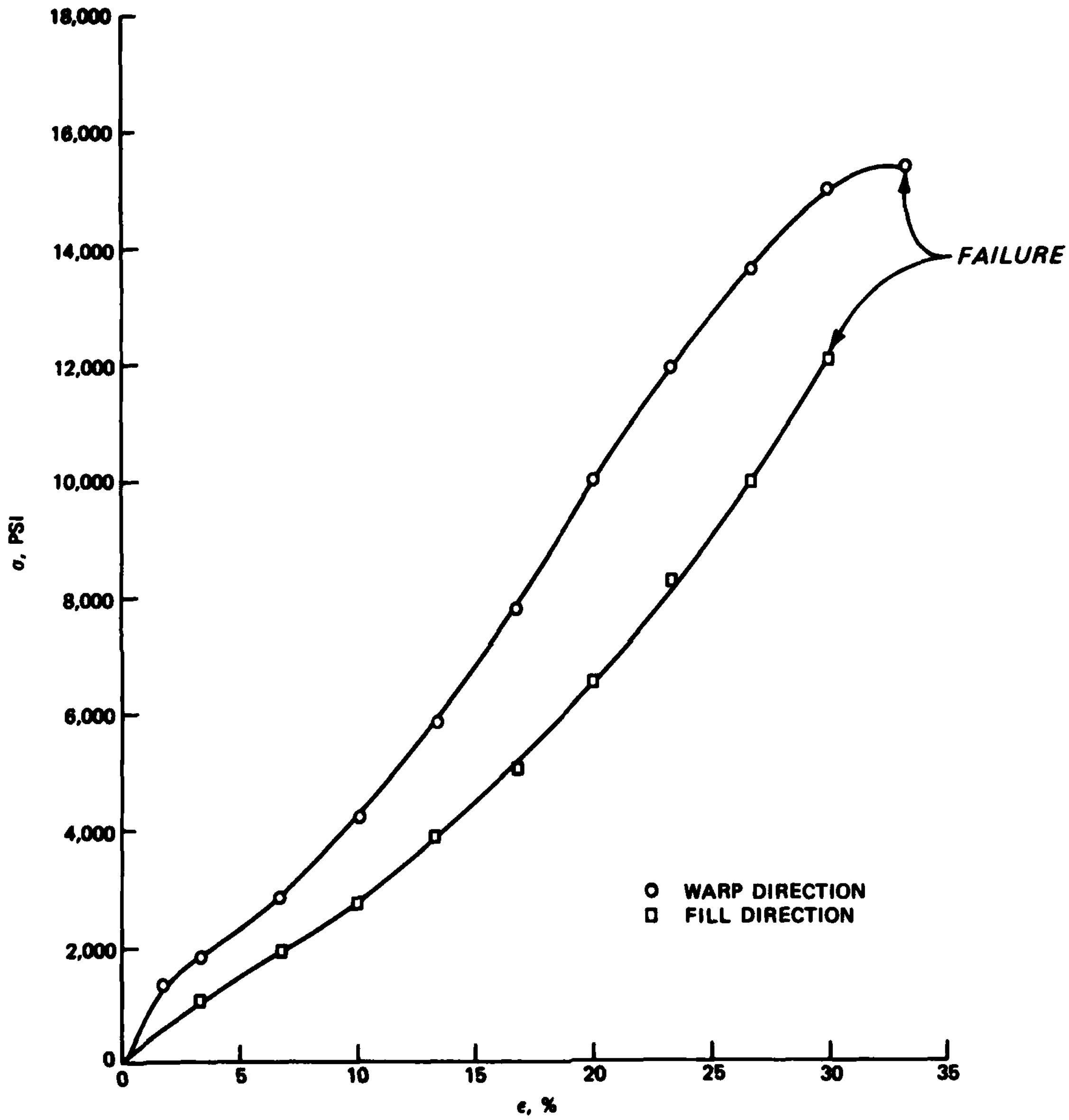


Figure 9. Uniaxial stress-strain characteristics of T-17 membrane (2-in. cut strip)

Table 4

Summary Layered Approach Construction Data

Layer Number	Average Height, ft	Total Height, ft	Remarks
6 (T)*	0.85		Layers 1-4 built with T-17 membrane; Layers 5 and 6 with T-16 membrane.
5	0.98		
4	0.98		Layers 1-3 built using Technique 1; Layers 4-6 used Technique 2.
3	1.36		
2	1.24		Lean clay soil was used in all layers.
1 (B)*	1.15	6.56	

* T = top layer; B = bottom layer.

Table 5

Bridge Deck Settlements During Period 1977-1981

Reference Point Location, Support	Initial Settlement in.	Other Settlement in.
1	0.18	1.32
2	0.60	3.24
3	0.66	3.48
4	0.36	1.86

Table 3

Summary of Layered Support Construction Data

Support Number	Layer Number	Nominal Size, ft	Average Height, ft	Total Height, ft	Remarks
1	2 (T)*	4 × 12	1.32		About 1 ft sand placed between bottom layer and excavation bottom.
	1 (B)*		1.35	2.67	
2	6 (T)	4 × 12	0.89		0.50 ft sand placed between bottom layer and excavation bottom; sandbags placed next to creek.
	5		1.36		
	4		1.38		
	3		1.38		
	2		1.12		
	1 (B)	6 × 14	1.39	7.52	
3	6 (T)	4 × 12	1.27		1.36 ft sand between bottom layer and excavation bottom; sandbags placed next to creek. Average CBR at base of excavation was 2.2 (from penetrometer readings).
	5		1.31		
	4		1.33		
	3		1.22		
	2		1.15		
	1 (B)	6 × 14	1.28	7.56	
4	5 (T)	4 × 12	1.40		1.73 ft sand placed between bottom layer and excavation bottom. Average CBR at base of excavation was 2.5 (from penetrometer readings).
	4		1.39		
	3		1.49		
	2		1.14		
	1 (B)	6 × 14	1.24	6.66	

* T = top layer; B = bottom layer.

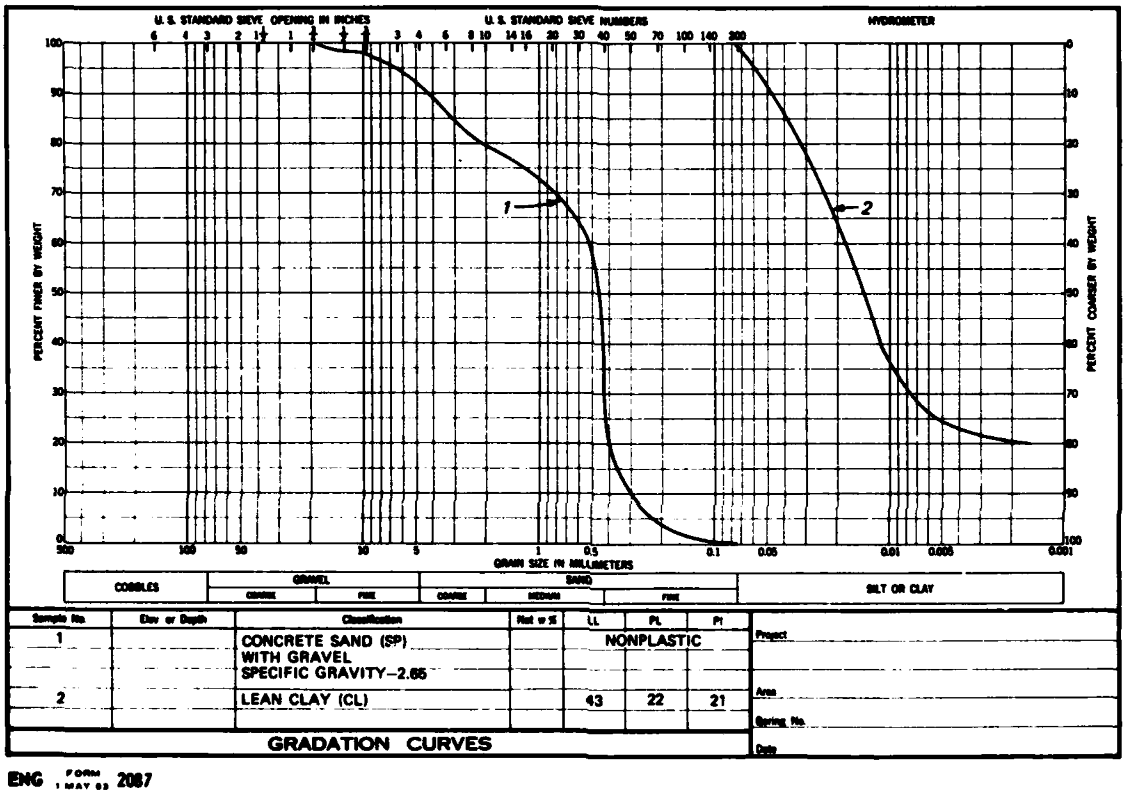


Figure 10. Soil gradations

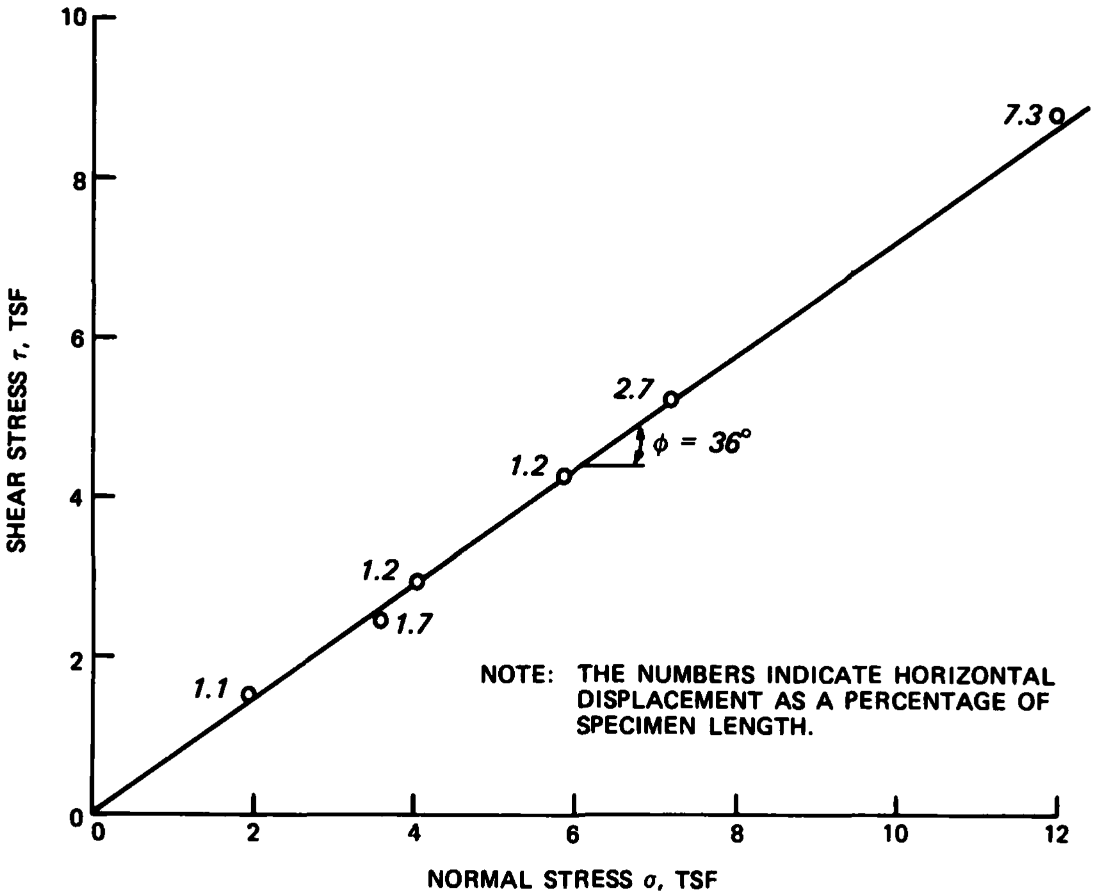


Figure 11. Direct shear test results for concrete sand at 100.0 pcf

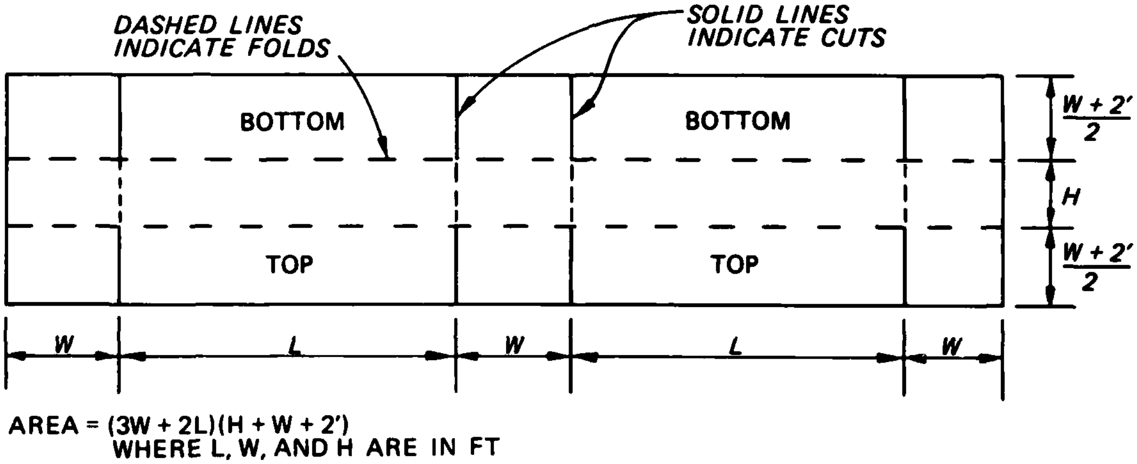
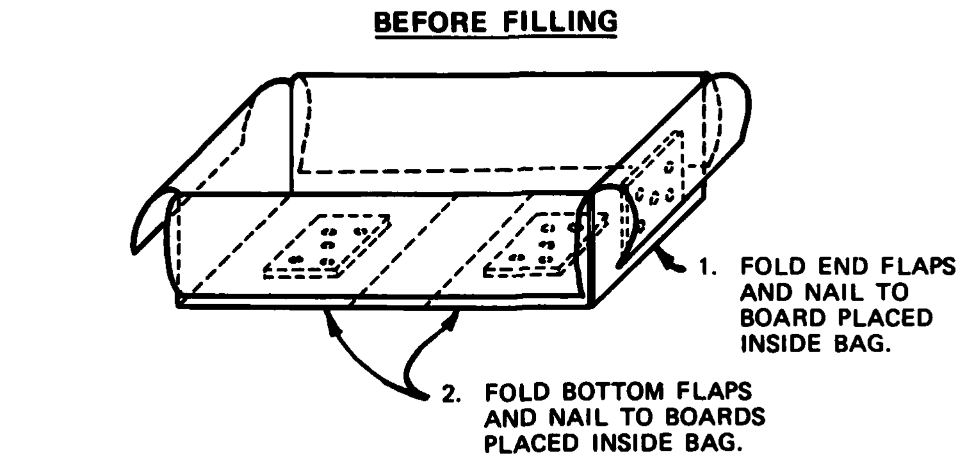


Figure 12. Membrane bag cutting pattern



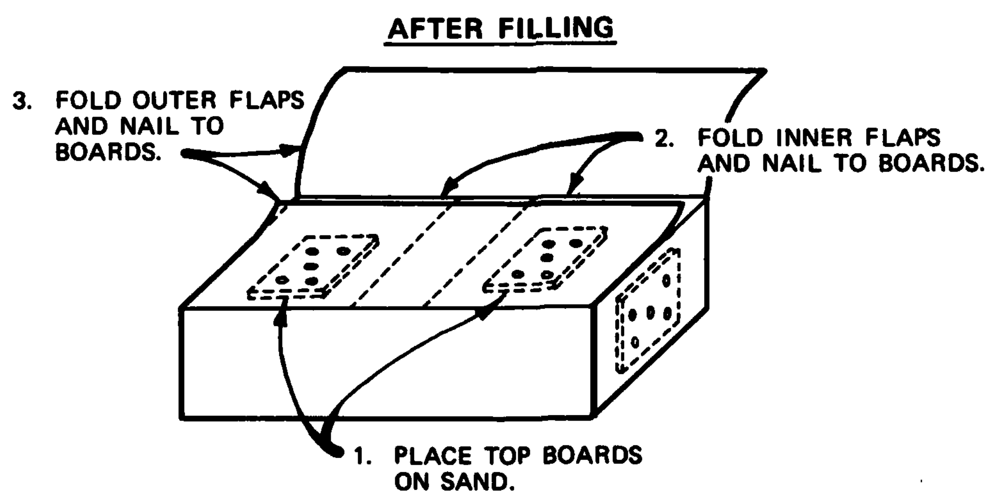


Figure 13. Membrane bag construction details

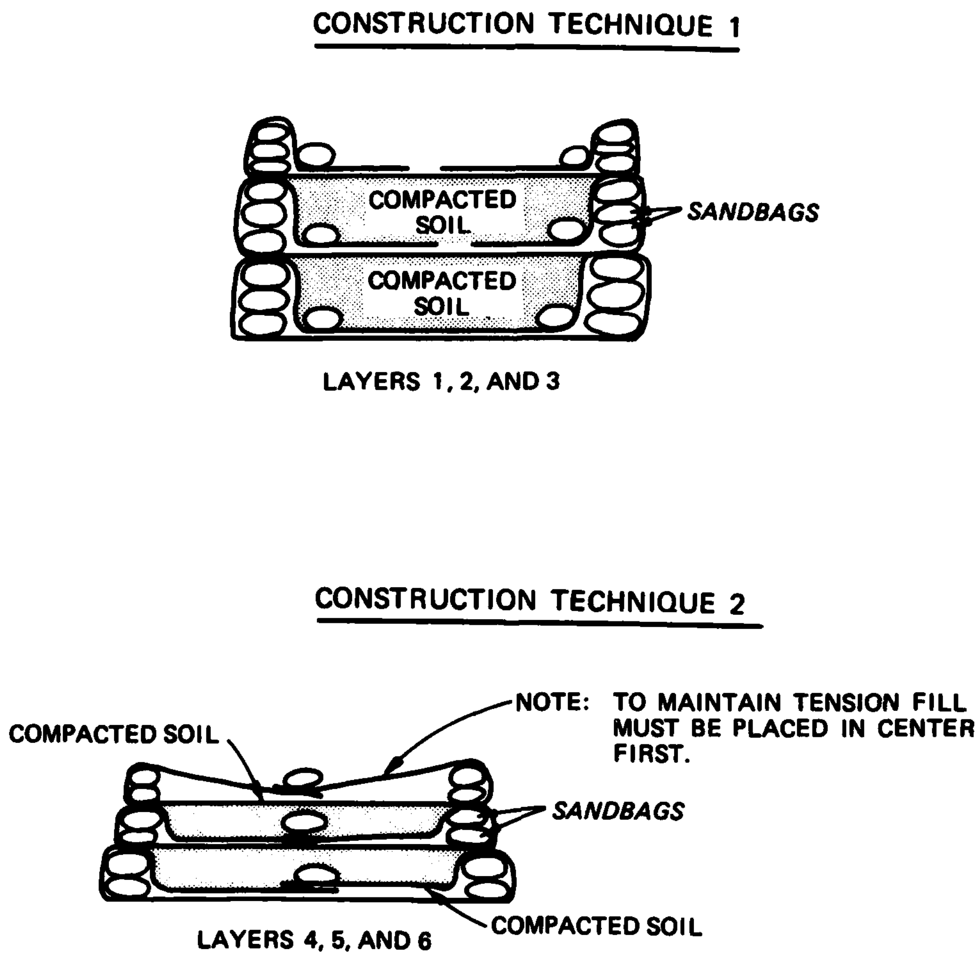


Figure 14. Approach construction techniques used

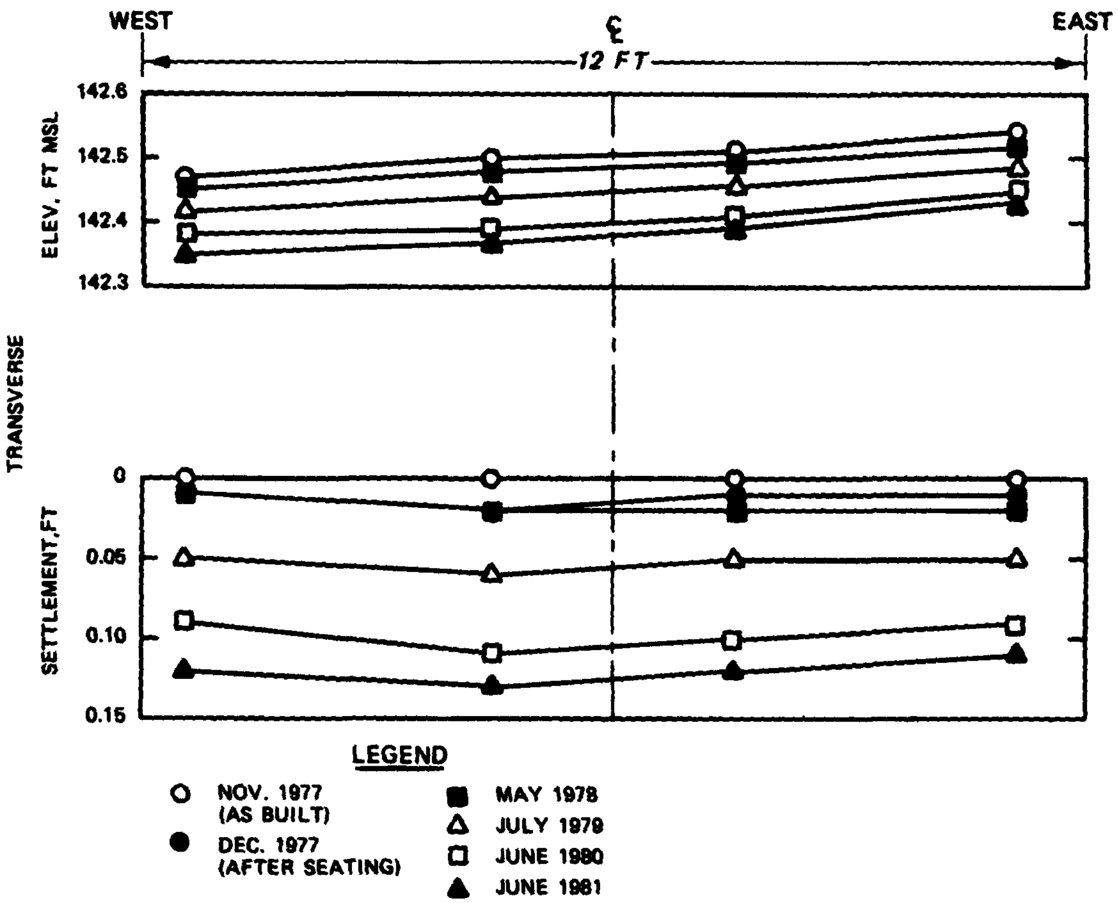


Figure 15. Tread above support 1

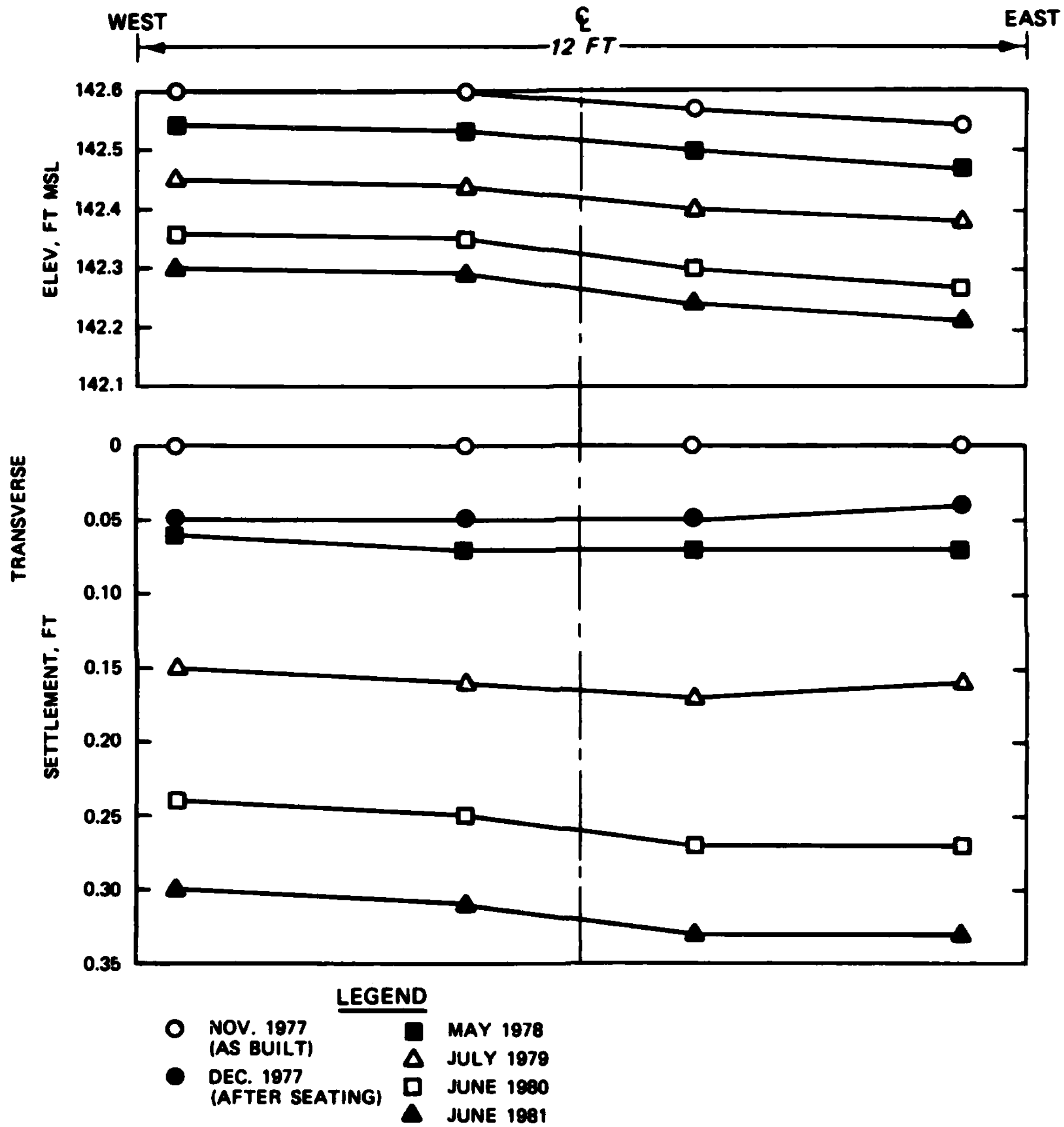


Figure 16. Tread above support 2

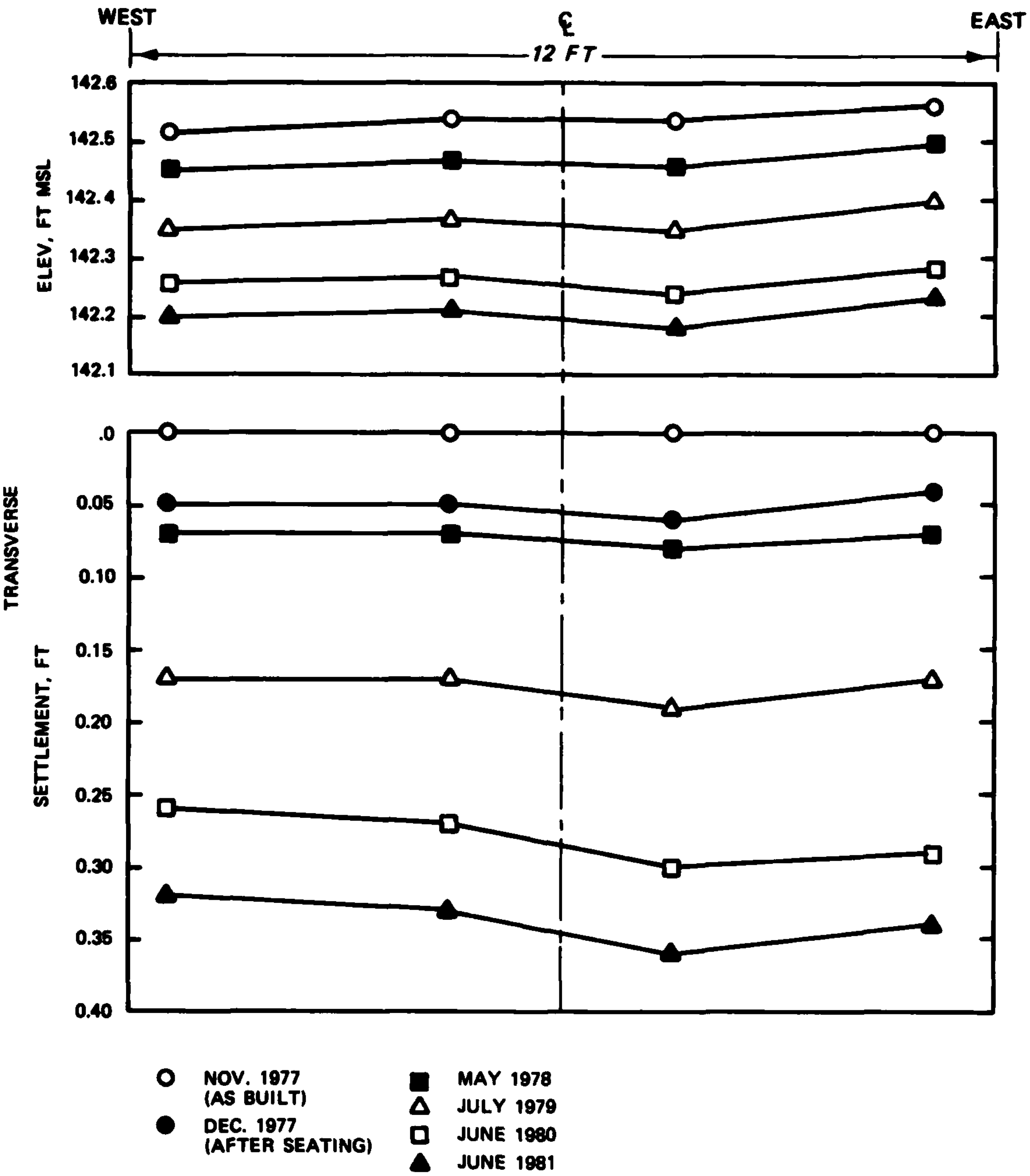


Figure 17. Tread above support 3

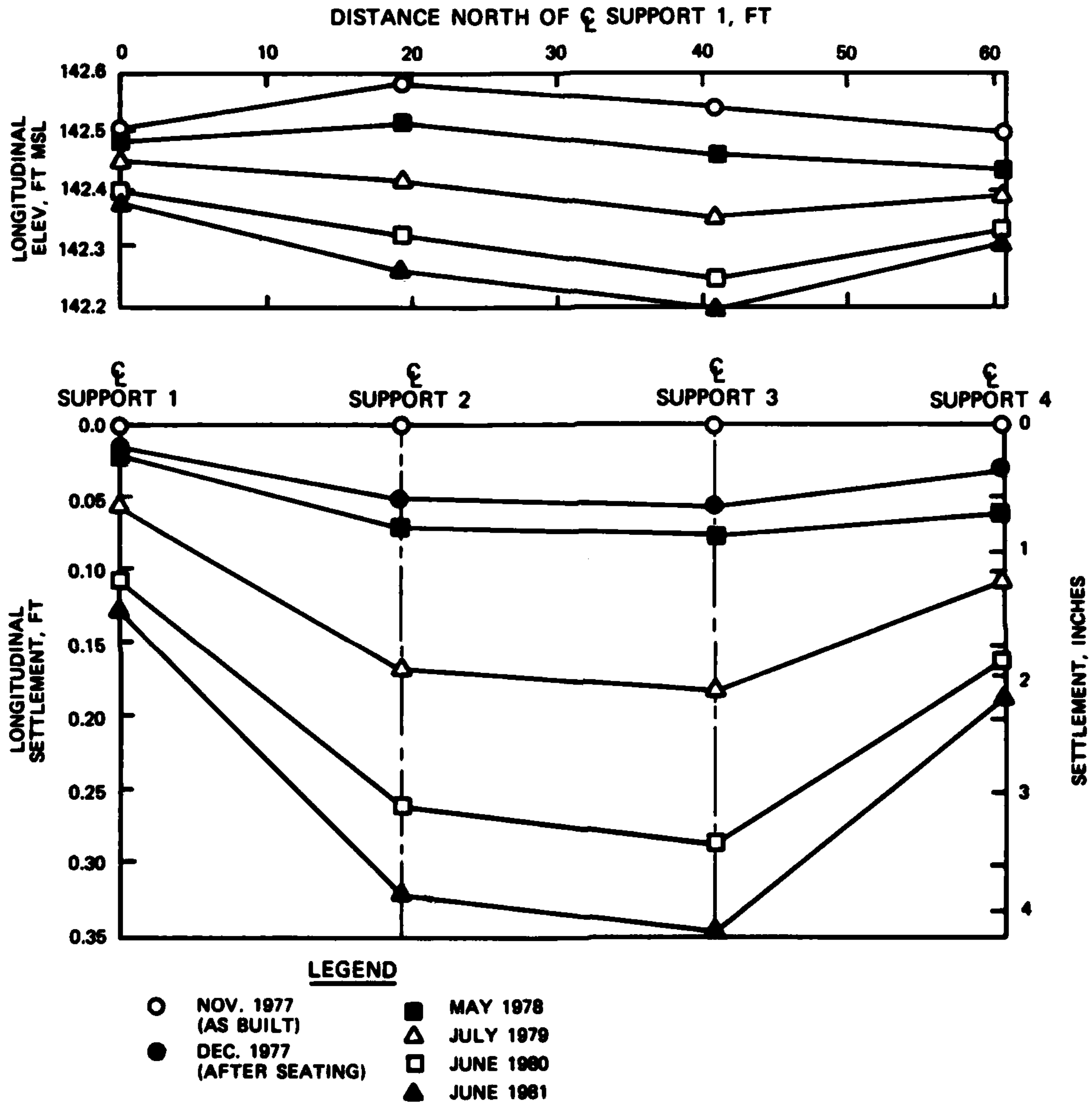


Figure 19. Summary of vertical bridge deck movement

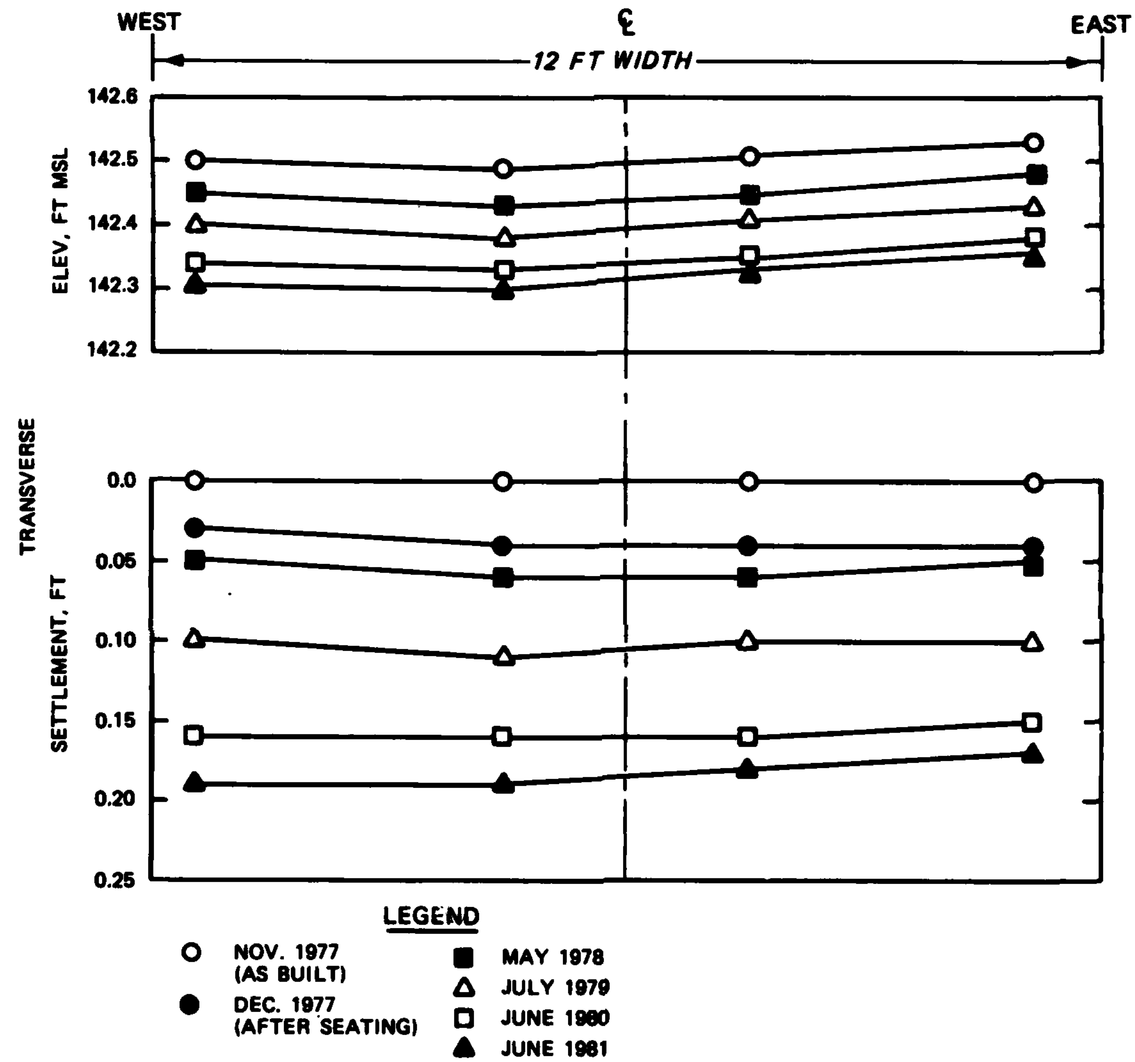


Figure 18. Tread above support 4

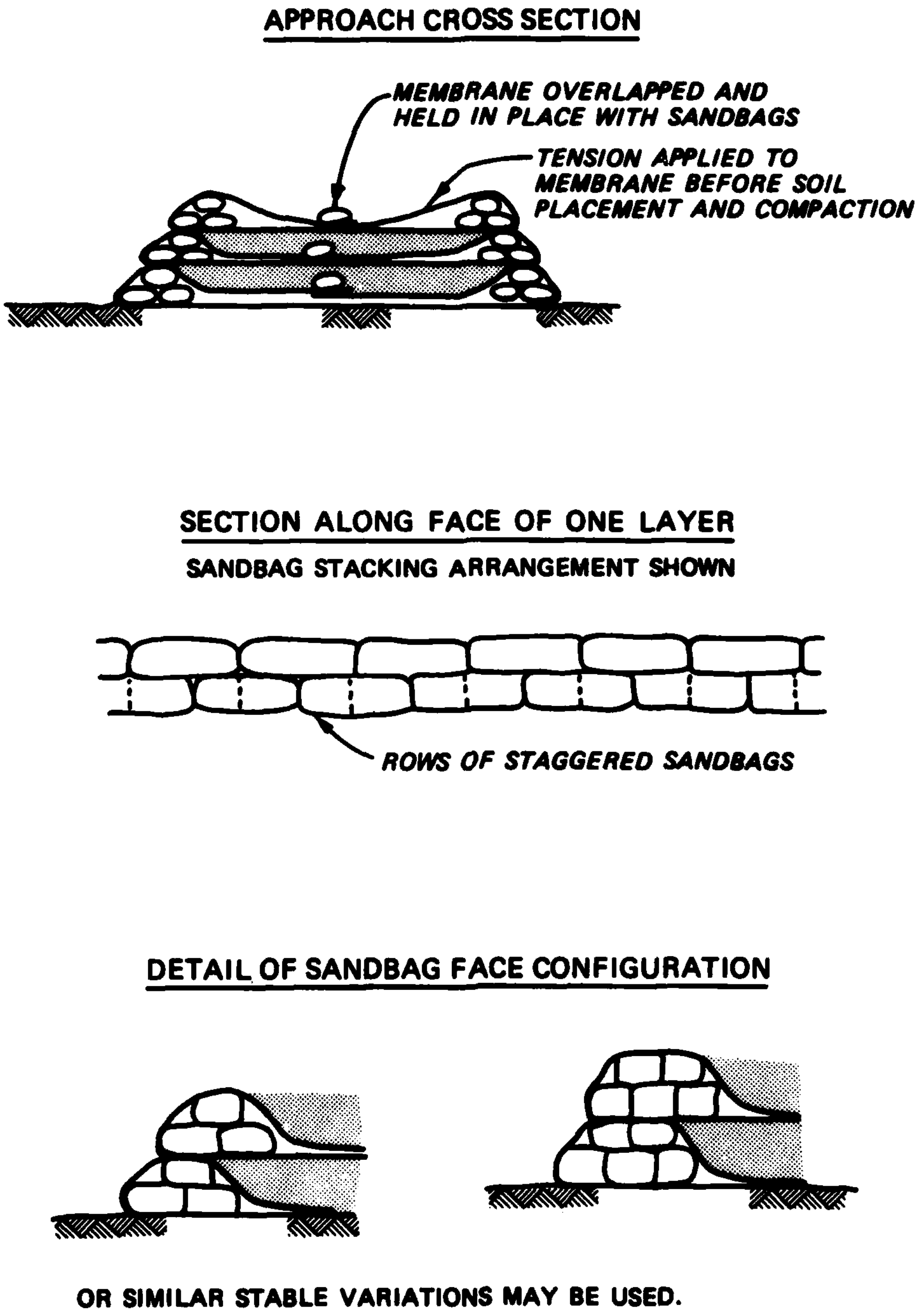


Figure 20. Recommended construction technique and sandbag configuration for layered approaches

Photo 1. Filling sandbags

Photo 2. Sand stockpile and filled sandbags

Photo 3. Cutting membrane pattern

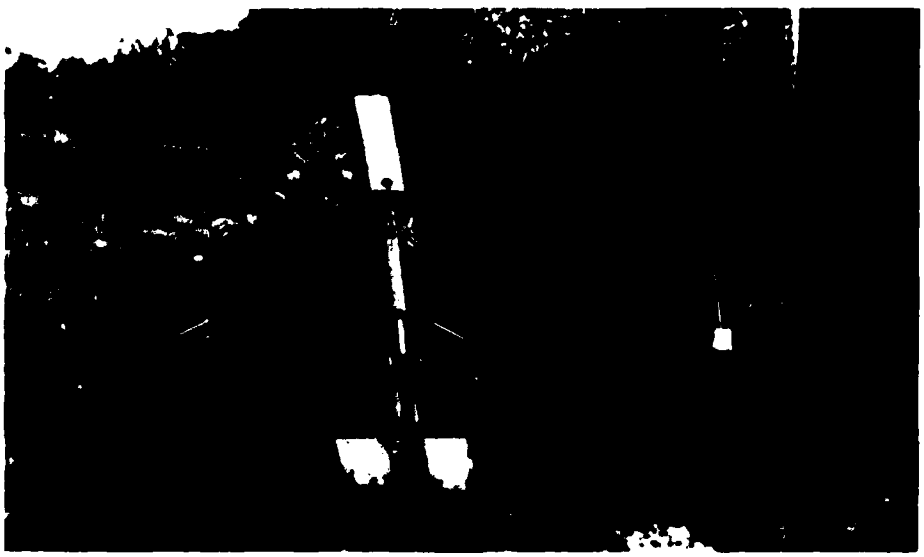


Photo 4. Excavating for layered support

Photo 5. Finishing bottom of excavation

Photo 6. Excavation with bottom membrane
and sandbags toward creek

Photo 7. Leveling sand in excavation

Photo 8. Typical first support layer showing sandbag form (note membrane flaps)

Photo 9. Compacting sand inside layer
(mechanical compaction)

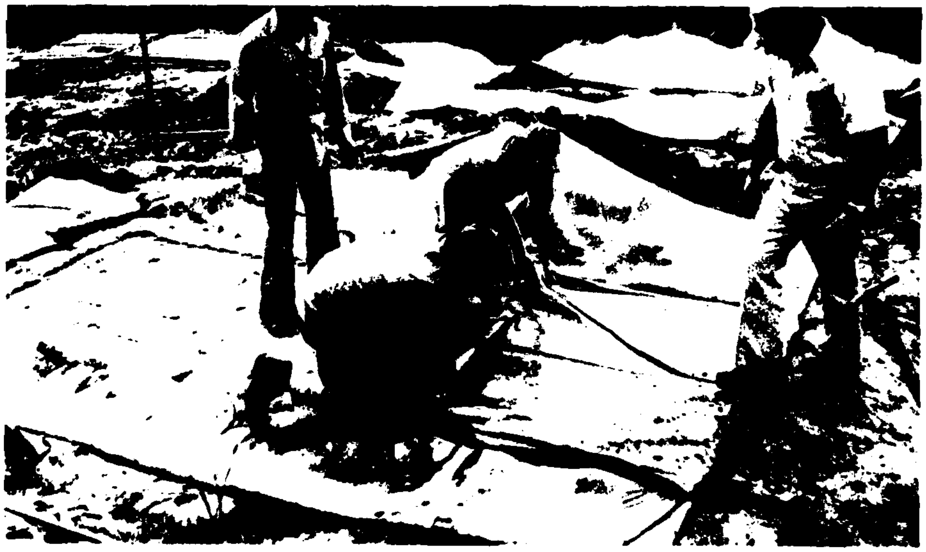


Photo 10. Closing flaps of membrane layer
(nailing membrane to plywood)

Photo 11. Closing flaps of membrane support layer (note plywood board)

Photo 12. Beginning second support layer

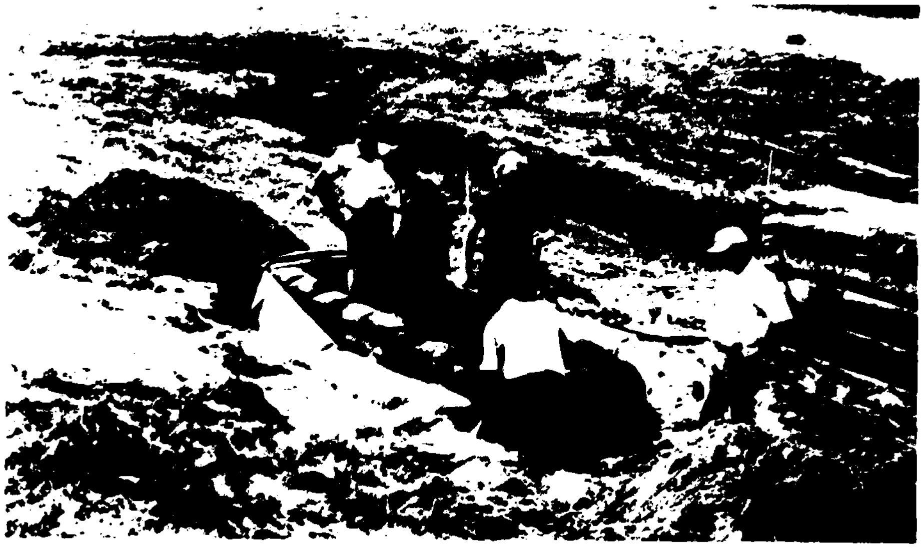


Photo 13. Upper support layer with sandbag form in place

Photo 14. Hand compaction in upper layer

Photo 15. Partially built supports
(support 1 open)

Photo 16. Completed layered supports

Photo 17. Bearing pads above supports

Photo 18. Stringer connection at interior supports

Photo 19. Stringer with lateral restraint above support

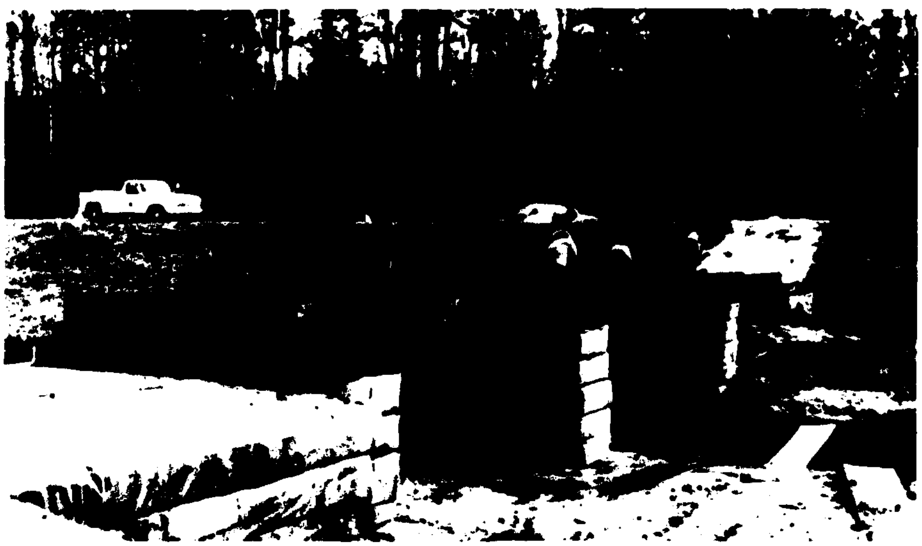


Photo 20. Stringers in place on supports

Photo 21. Placing decking on stringers

Photo 22. Cutting south approach

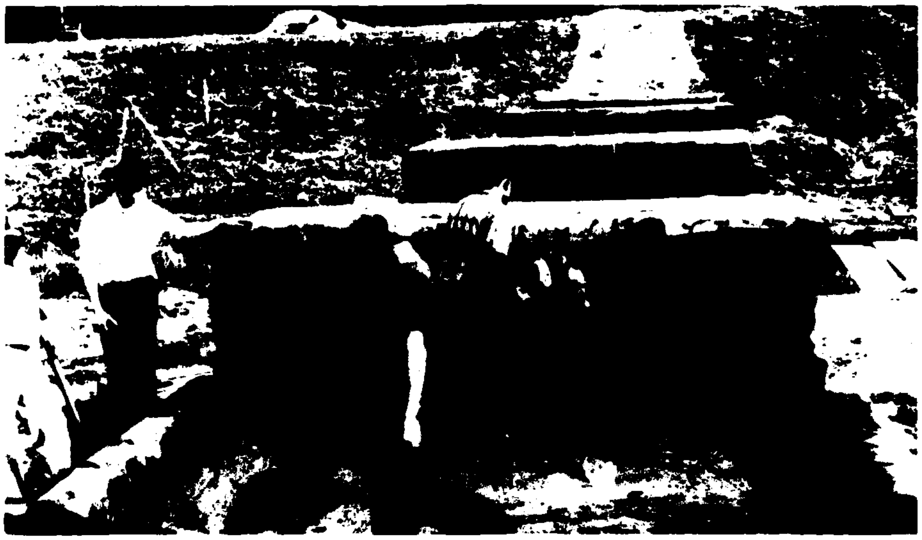


Photo 23. Constructing layered approach using Technique 1

Photo 24. Layered approach construction north of support 4

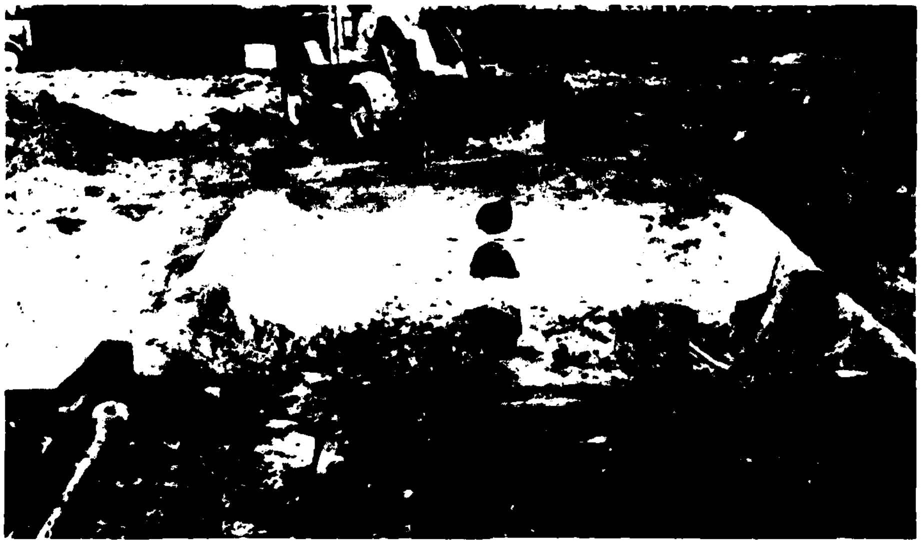


Photo 25. Layered approach using Technique 2 (before soil placement)

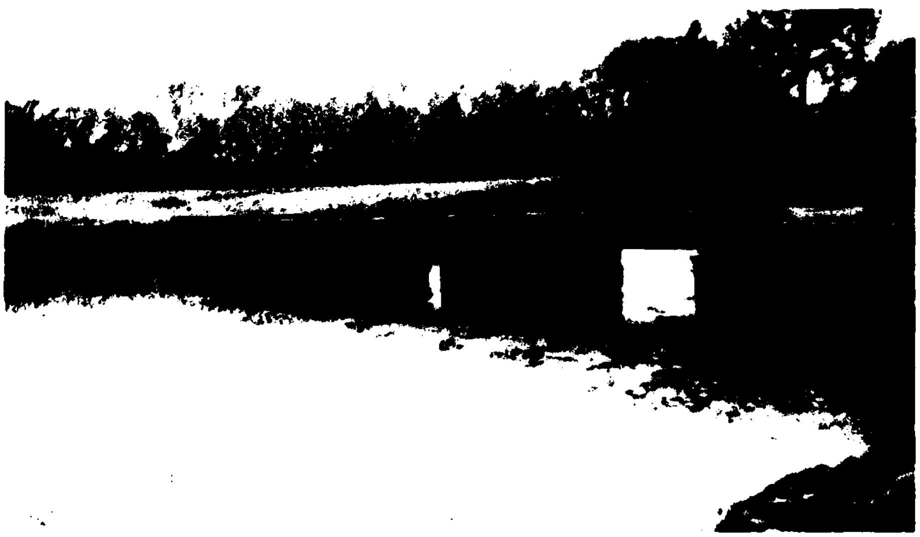


Photo 26. Completed bridge showing upstream cables

Photo 27. Seating superstructure on supports

Photo 28. Downstream view of completed bridge (February 1978)

Photo 29. Scour protection at support 2
(March 1981)

Photo 30. Layered approach at support 4
(May 1978)

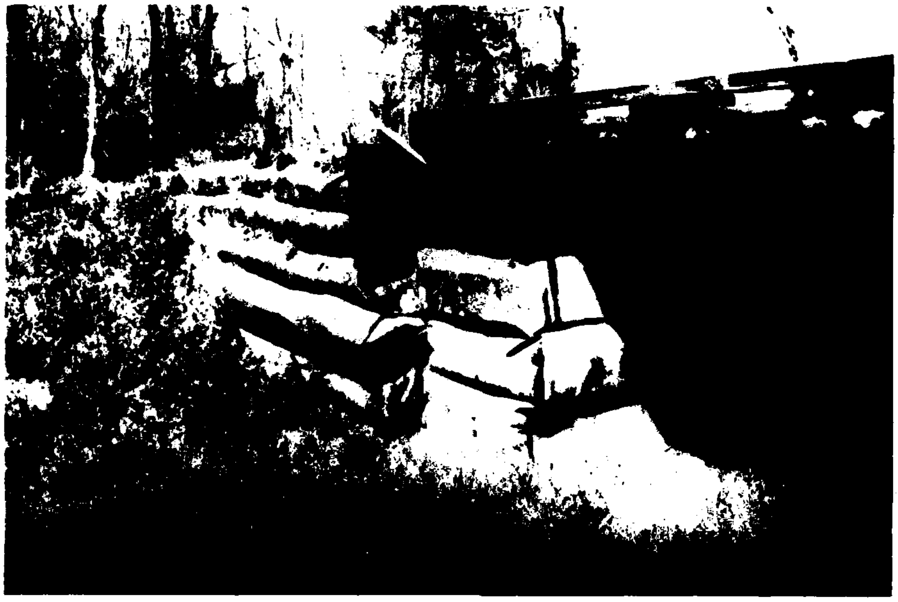


Photo 31. Layered approach, west side
(March 1981)

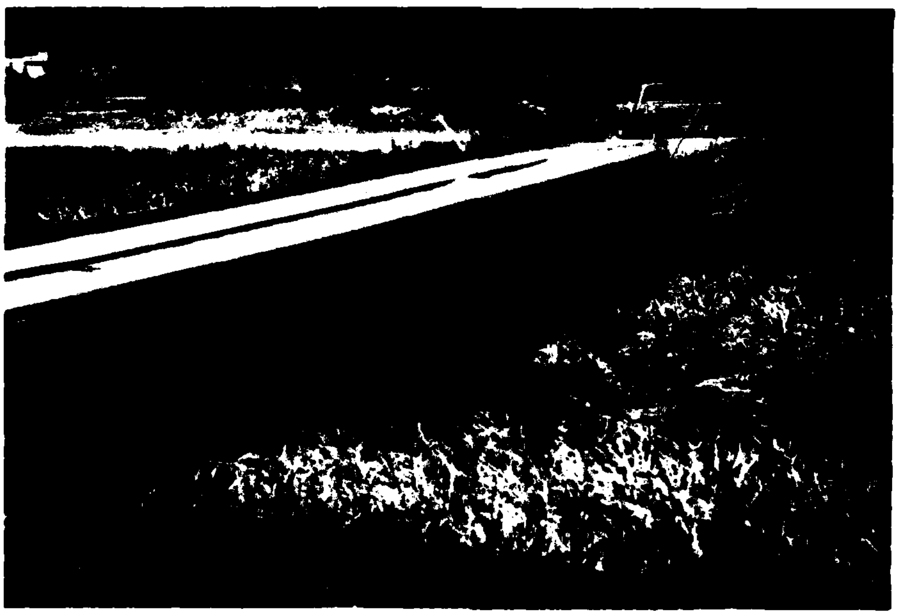


Photo 32. Layered approach and bridge, east
side (May 1981)

Photo 33. Close-up of east side, layered approach (February 1981)

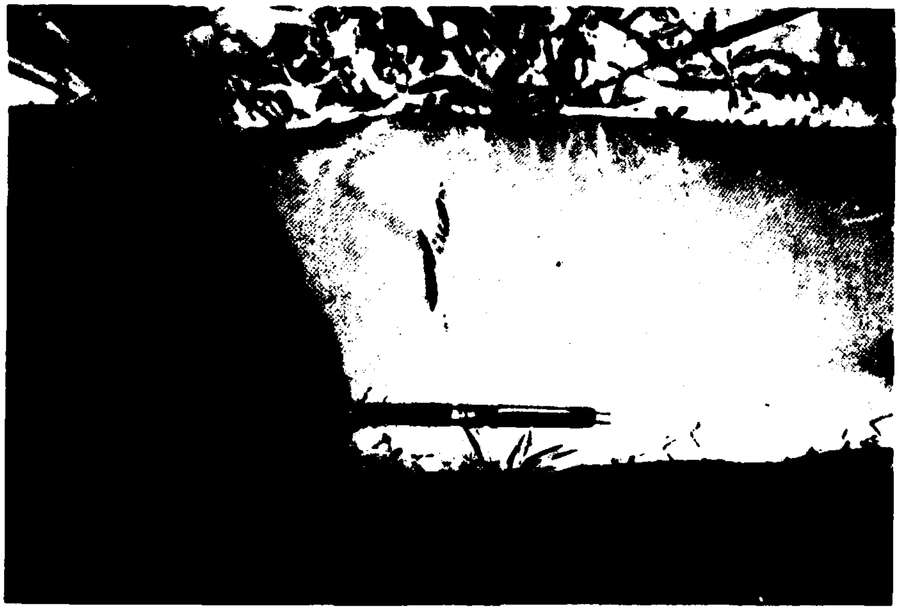


Photo 34. Close-up of west side of approach at layer 5 (T-16 membrane, May 1981)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report GL-82-7	2. GOVT ACCESSION NO. AD-A120563	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* MEMBRANE-SOIL COMPOSITE LAYERS IN THE DESIGN, CONSTRUCTION, AND PERFORMANCE OF AN EXPEDIENT BRIDGE AND APPROACH		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) George L. Regan		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Geotechnical Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project A4A762719AT40, Task CO, Work Unit 003
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE September 1982 13. NUMBER OF PAGES 64
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Expedient construction
Membranes (Roads)
Military bridges
Military operations
Soil (Construction material)

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

There is a definite need to make use of locally available materials in construction to minimize time and cost of construction. This report described a technique for constructing bridge approaches, abutments, and piers using locally available soils and military stock membrane (T-16 and T-17). The construction of the bridge described in this report involves confining sand with T-16 and T-17 membrane to form the various structure units. After the approach, abutment, and piers were constructed, treated timber was used

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

20. ABSTRACT (Continued).

in construction of the stringers, decking, and tread.

The bridge was constructed with a small labor force and a minumum amount of equipment. The construction was simple and fast, thus making it readily adaptable to conditions faced in the theater of operations.

The bridge was built in 1977, and the performance was recorded for a period of approximately five years. During this time only minor scour problems developed around the piers and these problems were handled with a minimum of maintenance.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Regan, George L.
Membrane-soil composite layers in the design, construction, and performance of an expedient bridge and approach / by George L. Regan (Geotechnical Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. ; available fron NTIS, 1982.
23, [41] p. : ill. ; 27 cm. -- (Technical report ; GL-82-7)
Cover title.
"September 1982."
Final report.
"Prepared for Office, Chief of Engineers, U.S. Army under Project A4A762719AT40, Task CO, Work Unit 003."
Bibliography: p. 23.

1. Membranes (Technology). 2. Military bridges. 3. Military engineering. 4. Soils. I. United States. Army. Corps of Engineers. Office of the Chief of Engineers.

Regan, George L.
Membrane-soil composite layers in the design : ... 1982.
(Card 2)

II. U.S. Army Engineer Waterways Experiment Station. Geotechnical Laboratory. III. Title IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; GL-82-7.
TA7.W34 no.GL-82-7